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SST Technology
Follow-On Program-Phase I

DEVELOPMENT AND EVALUATION OF FUEL TANK SEALANTS

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D6-60221

January 15, 1972

FINAL REPORT
Task 2

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16. Abstract
Since 1961 Boeing has conducted a continuous search for a fuel tank sealant for the U.S.A. supersonic transport. Testing began in 1965 and from that time to the present 16 sealant systems were screened. Only one, a flourosilicone, was found worthy of extensive testing. A program was instituted which involved measuring important physical properties before and after exposure to expected environments. The program included functional testing of sealed tanks. Results are reported for exposure for more than 20,000 hours at 426°-441° F in fuel vapor in an accelerated cycle, more than 2000 of such hours in a flight cycle, and more than 1500 of such hours in a sealed tank. As deficiencies were recognized, the sealant supplier was notified and steps were taken to eliminate the problem. Preliminary specifications for procurement and process controls have been prepared.

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PREFACE

Among the agencies participating in this program by furnishing samples for test and doing developmental work were Dow Corning, General Electric, Minnesota Mining and Manufacturing, Products Research and Chemical Corporation, Mosites, and the Air Force Materials Laboratory. The Boeing Company is especially grateful to the Dow Corning Company for its continuous interest, diligence, and close cooperation in producing a fuel tank sealant for the supersonic transport.

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1.0 INTRODUCTION

A major technological requirement of the U.S.A. supersonic transport program was to ultimately provide an aircraft to the commercial airlines which would be competitive from a maintenance standpoint with the presently used subsonic aircraft. The need for an elastomeric material to function as an integral fuel tank sea[illegible] [illegible]mercial supersonic aircraft necessitated an extensive research and development [illegible]vity by both The Boeing Company and its material suppliers.

The polysulfide-type sealants now used in subsonic jet aircraft have performed satisfactorily for up to 45,000 hr of flight time on individual aircraft. Fuel tank leakage caused solely by sealant degradation is almost nonexistent, and if mechanical damage to the sealant occurs, repairs are easily carried out.

Integral sealant material for the SST imposes additional technical and environmental requirements beyond those of the subsonic polysulfide sealant. It has to be able to accommodate structural strains over a temperature range of -50° to +450° F under tank conditions of hot fuel and fuel vapor. It has also to adhere to titanium alloy 6Al-4V and be inert to both the titanium structural alloy and the fluids encountered in manufacturing and flight operations. Finally, it has to function satisfactorily for at least 50,000 flight hours. A search for such a sealant was begun in 1961, through literature search and supplier contacts. It was obvious, when the SST fuel tank sealing program was initiated in 1965, that only two elastomeric polymer systems could reasonably be considered as leading candidates on the basis of thermal stability and resistance to fuels. These were the fluorocarbons and the fluorosilicones. Every available sealing system based on these polymers, as well as some others in use on supersonic airplanes, were investigated to ascertain their suitability. To date 16 such systems have been screened, only four of which have the required thermal stability and compatibility with titanium. These are fluorosilicones DC 94-002, DC 94-516, DC 77-028 (an improved version of DC 94-516), and fluorocarbon AFML 397. Sealing systems eliminated were a Viton-based material from Products Research and Chemical Corporation; 3M's EC-5106, XC-5407, and EC 2332; Dow Corning's fluorosilicones 94-508, 94-512, 94-026, and 94-030; two unidentified systems from General Electric; and two Viton-based systems from the Air Force Materials Laboratory.

Even though their thermal and fuel resistance are excellent, the fluorocarbons such as the Fluorels and Vitons have a tendency to cause stress corrosion of titanium and currently depend on being in solution for use. Volatilization of the solvent precludes their effectiveness as a filleting sealant, since they must be applied in thin layers. The fluorocarbons also have poor low-temperature flexibility.

It was not until 1967 that the Dow Corning Company was successful in producing a fluorosilicone sealant which would operate continuously at temperatures greater than 400° F. The major evaluation effort has been concentrated on this sealant and its improvements.

Dow Corning and Boeing worked together closely to further develop the fluorosilicone system with the emphasis on improving reliability of adhesion and repairability, and creating satisfactory faying surface and injection sealants. Primary sealing of the SST was to be by means of fillet seals, but in many situations it was necessary to use fillet sealing in conjunction with other sealing methods. The faying surface sealant passed laboratory tests but was suspect due to visible channels through it and failure to seal the cover of a test tank. The problem with injection sealant was one of excessive thermal expansion, which caused it to extrude and to tear itself and the fillet seal covering it.

The basic fillet sealant, designated DC 77-028, was varied to obtain properties that would make it more suitable for faying surface and injection or prepack sealing by using different fillers and combinations of fillers. The faying surface sealant was designated DC 77-053, and the injection or prepack sealant was designated DC 77-066. Figure 1 shows how these sealants are used.

Another obstacle to determination of the suitability of a fuel tank sealant material was the lack of physical property requirements. The only criteria available were derived from an examination of physical properties of sealants proven to be satisfactory from a functional standpoint. On this basis, Boeing established the following fillet sealant requirements under any environmental condition encountered and after 50,000 hr of service life:

- Design Requirements:

Adhesion to 6Al-4V titanium, peel and tear	6 lb/in., 85% cohesive failure, minimum
Tensile elongation	15% minimum

- Control Requirements:

Shore A hardness	Less than 20 points change
Weight change	Less than 20%
Volume change	Less than 10% loss
Deflection simulation (0.011-in. deflection)	Less than 30% tear after 100 cycles
Leakage (picture frame)	No leaks

- Manufacturing Requirements:

Flow (slump)	0.5 in. maximum in 2 hr
Extrusion rate	15 g/min, minimum
Cure	Less than 160° F
Working life	At least 0.5 hr
Repairability (peel test)	6 lb/in., 85% cohesive failure, minimum

Search for a backup to the fluorosilicone system was being conducted under a contract with Products Research and Chemical Corporation to develop into a practicable sealant a fluorocarbon system pioneered by the Air Force Materials Laboratory. Negotiations were

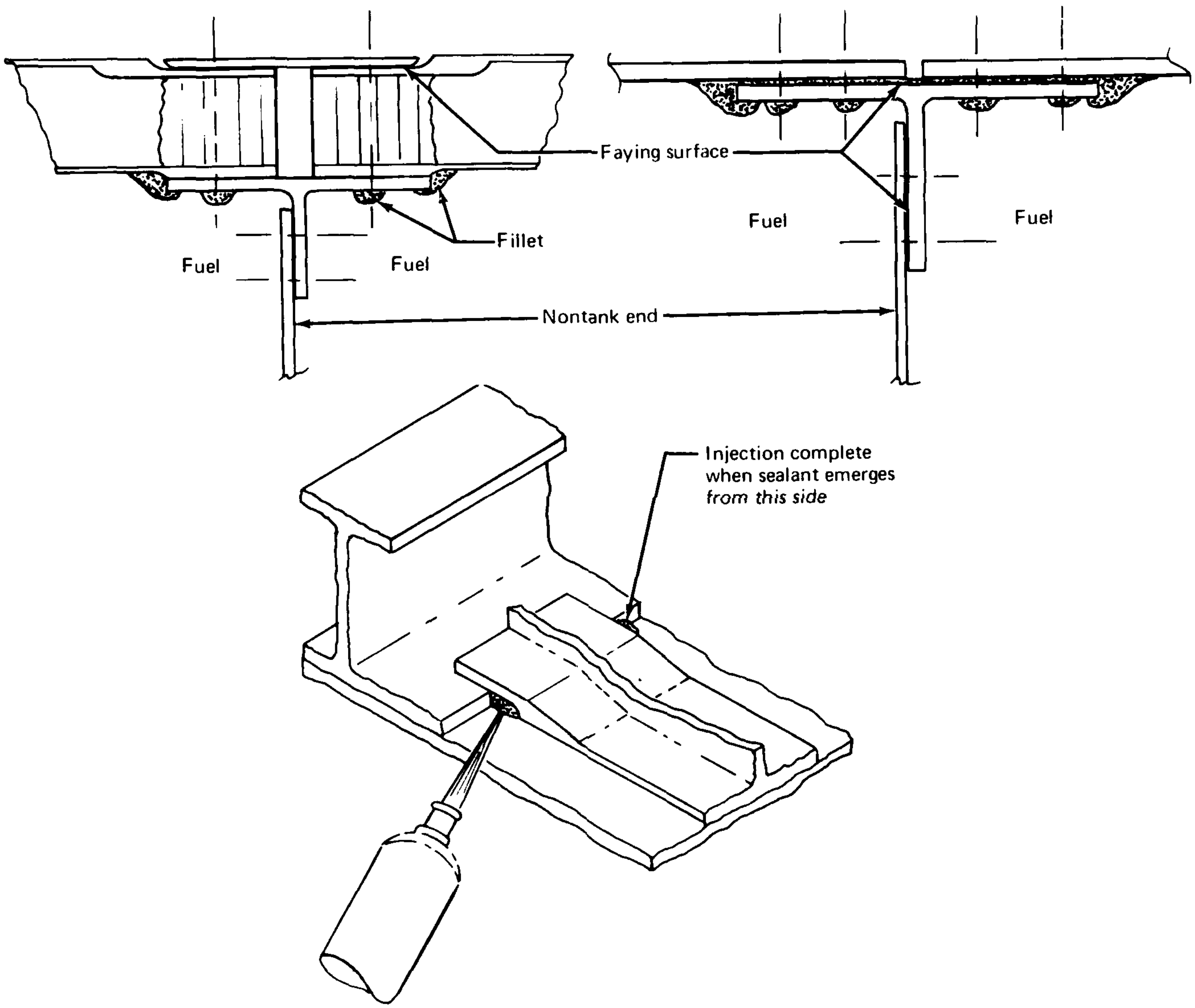

FIGURE 1.–TYPICAL FILLET, FAYING SURFACE, AND INJECTION SEALING

under way with Horizons Research and Firestone to further develop fluorinated phosphazenes. Both NASA and AFML were active in funding fuel tank sealant development programs. These programs were followed closely by Boeing.

The complete full-scale fuel tank sealant development program in effect during the SST contract is shown in figure 2. Following the termination of the SST, contract DOT-FA-SS-71-12 was awarded to Boeing by the Department of Transportation to continue cycling and testing of specimens in test at that time. The program was aimed at continuing environmental testing to verify that the modifications made to the fluorosilicone sealant to date have provided beneficial results. Testing included basic tensile properties, adhesion, and cyclic strain effects.

In addition testing was continued on the two tanks which were being used to expose sealant as it would be used on the airplane. One was representative of SST structure only in that it was titanium. It was being used to check repair methods. The other was designed to be representative of SST structure and sealing techniques. It was to identify any application or functional problems. Slightly over 1000 hr of testing in fuel vapor at elevated temperature had been accumulated, but there had been no inspection. At the beginning of the follow-on program the tanks were inspected, and tank 3 was repaired and returned to cycling load and environmental exposure.

This report includes only the fuel tank sealant development and evaluation portion (designated "ST-M Chemical") of figure 2 and the results of the follow-on program covered by contract DOT-FA-SS-71-12.

The preliminary materials purchase control specification, XBMS 5-50, and the process control specification, XBAC 5533 for the fuel tank sealant, are included as appendixes.

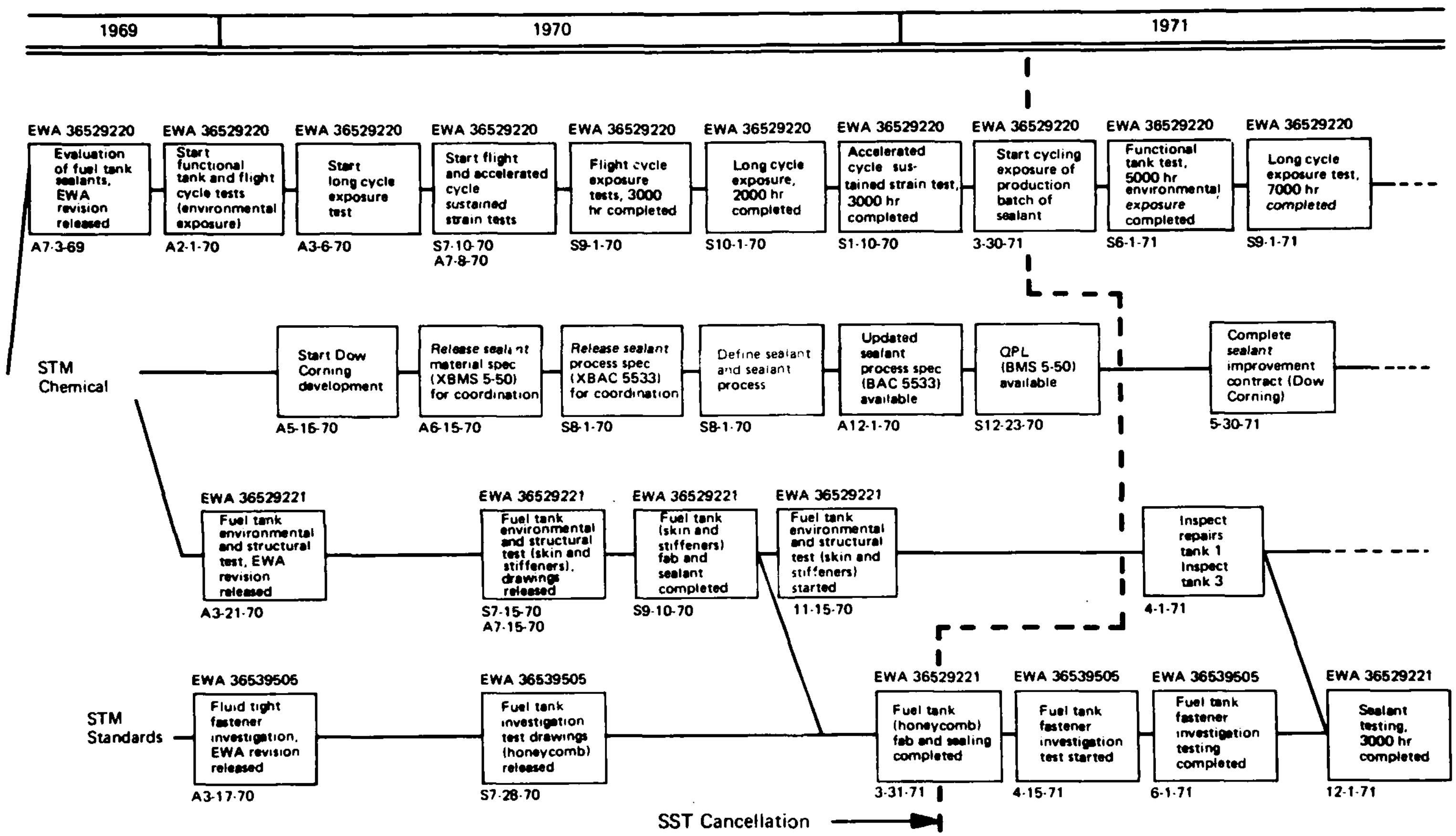

FIGURE 2.–SST SEALANT DEVELOPMENT PROGRAM

2.0 TEST METHODS AND PROCEDURES

The general approach was to subject test specimens to various static and dynamic exposures and measure changes in physical and mechanical properties. Responses of the sealant to the exposures were used as indications of useful life and deficiencies of the basic material or system. Functional tests, which measured sealing ability depending on all properties of the total system, were also conducted to evaluate the practical aspects of the sealant's use.

2.1 CYCLING ENVIRONMENTAL EXPOSURES

Two principal cycling environments are utilized, namely, flight and accelerated. Tanks were exposed to cycles similar to the accelerated cycle. Some environments were also imposed to simulate special conditions.

2.1.1 Flight Cycle

The simulated flight cycle, figure 3, provides about 50 hr per week of elevated-temperature fuel vapor exposure. The equipment is shown schematically in figure 4 and pictorially in figure 5. The loaded specimen rack is shown in figure 6.

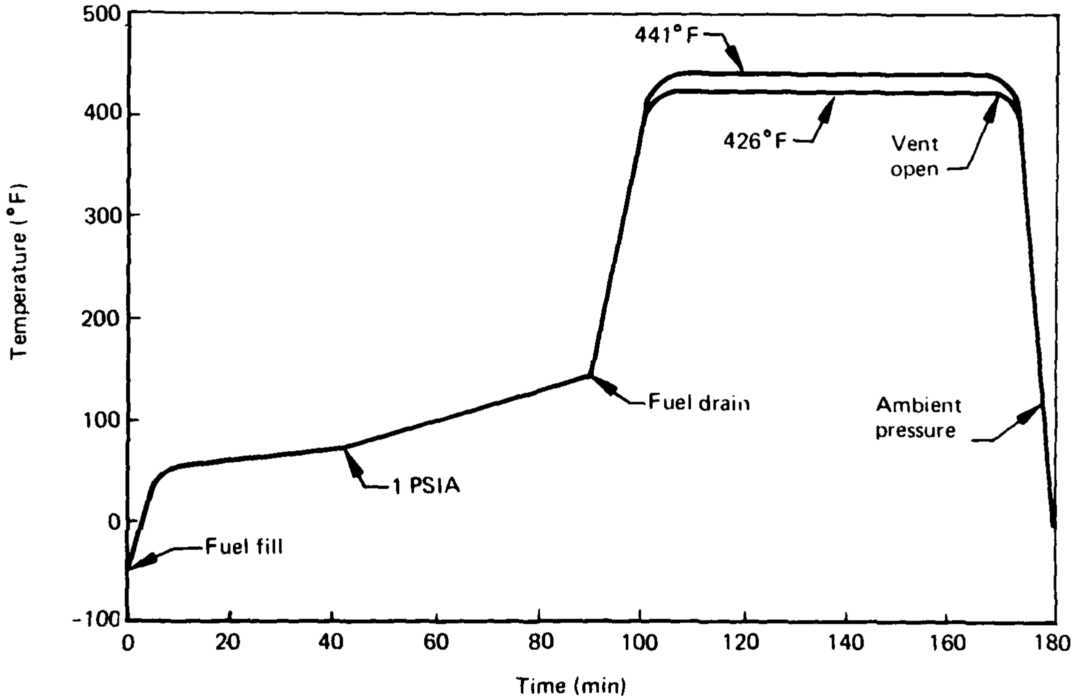

FIGURE 3.–STANDARD FLIGHT CYCLE

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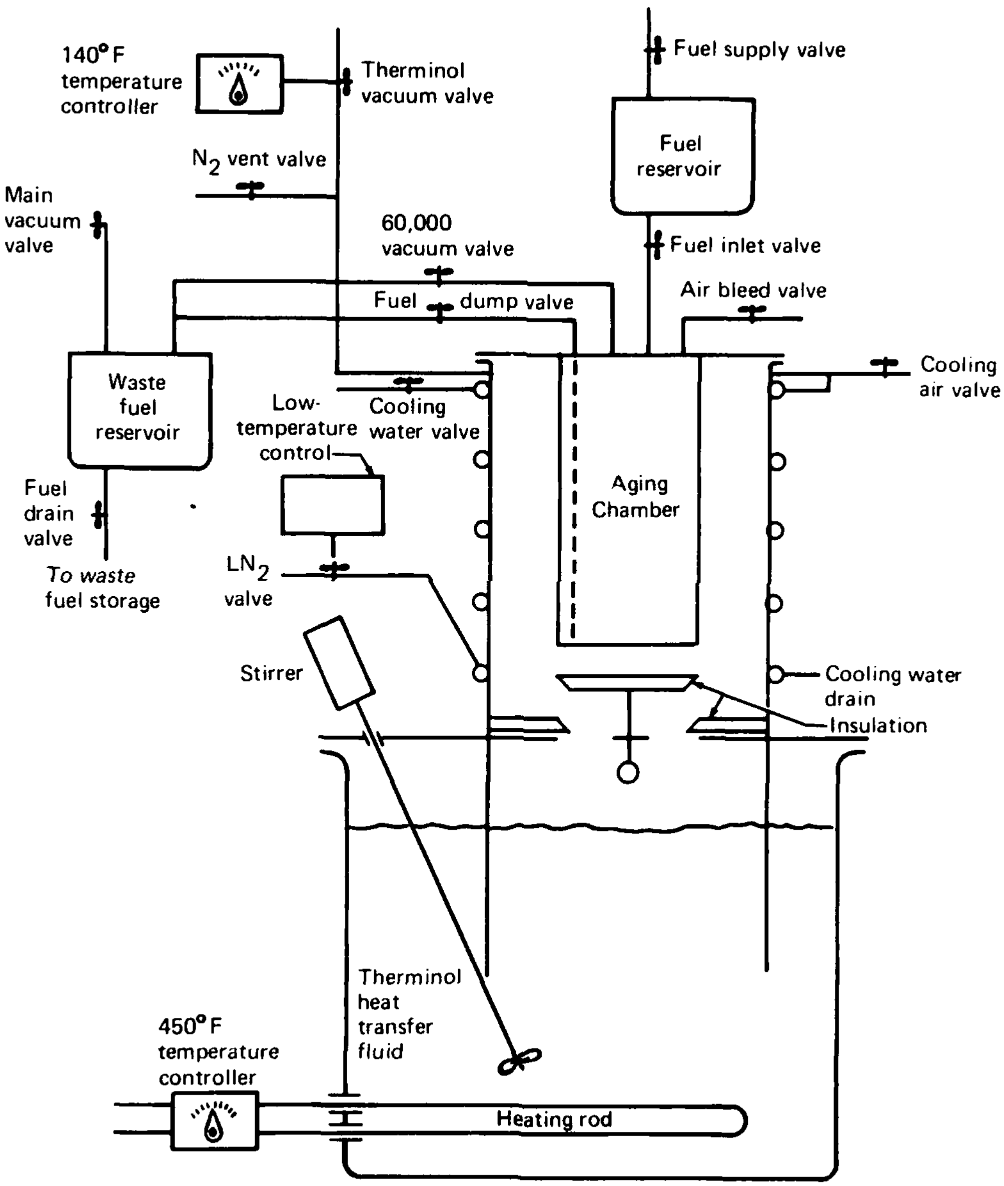


FIGURE 4.—FLIGHT CYCLE APPARATUS

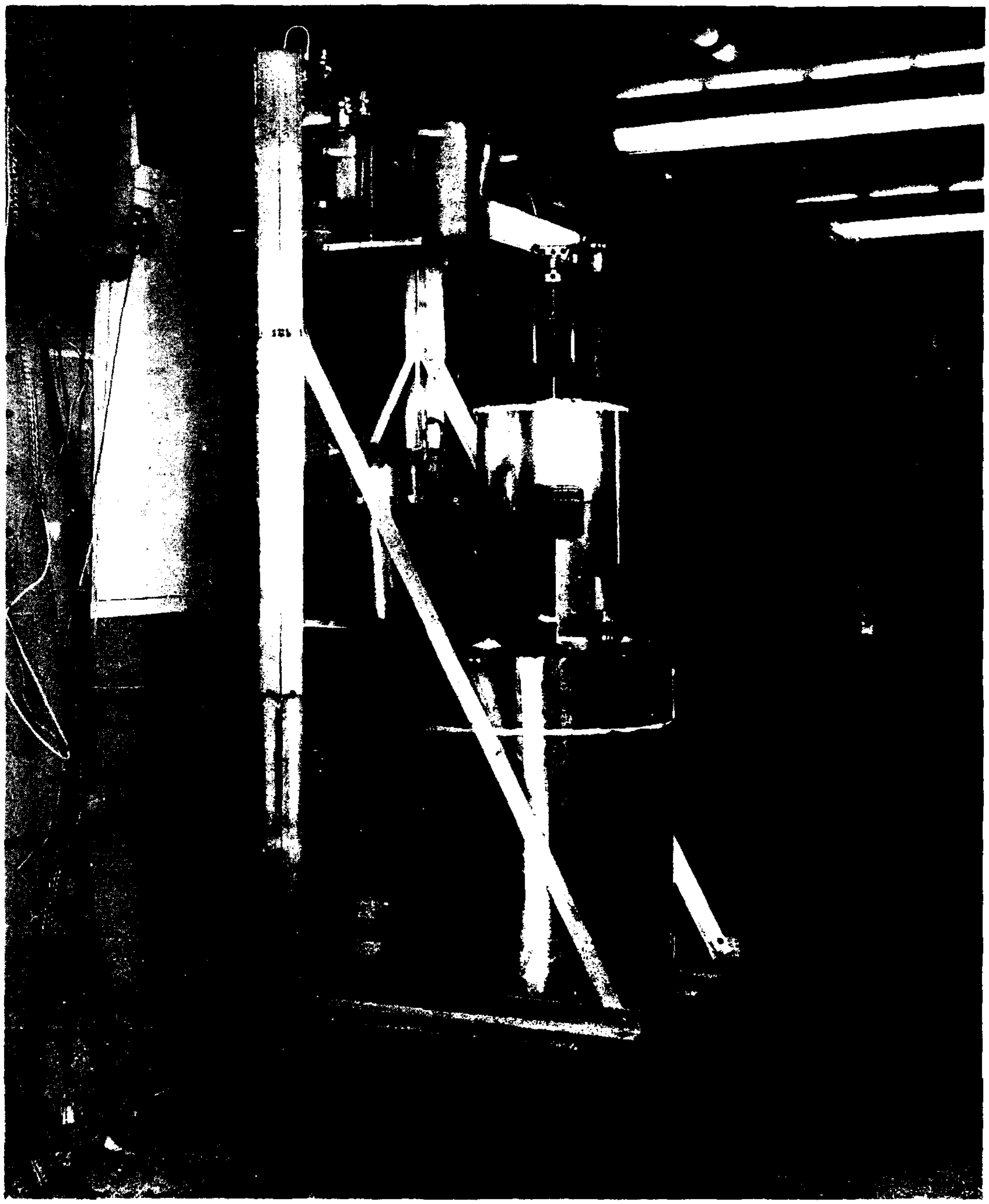


FIGURE 5.–FLIGHT CYCLE APPARATUS WITHOUT INSULATION

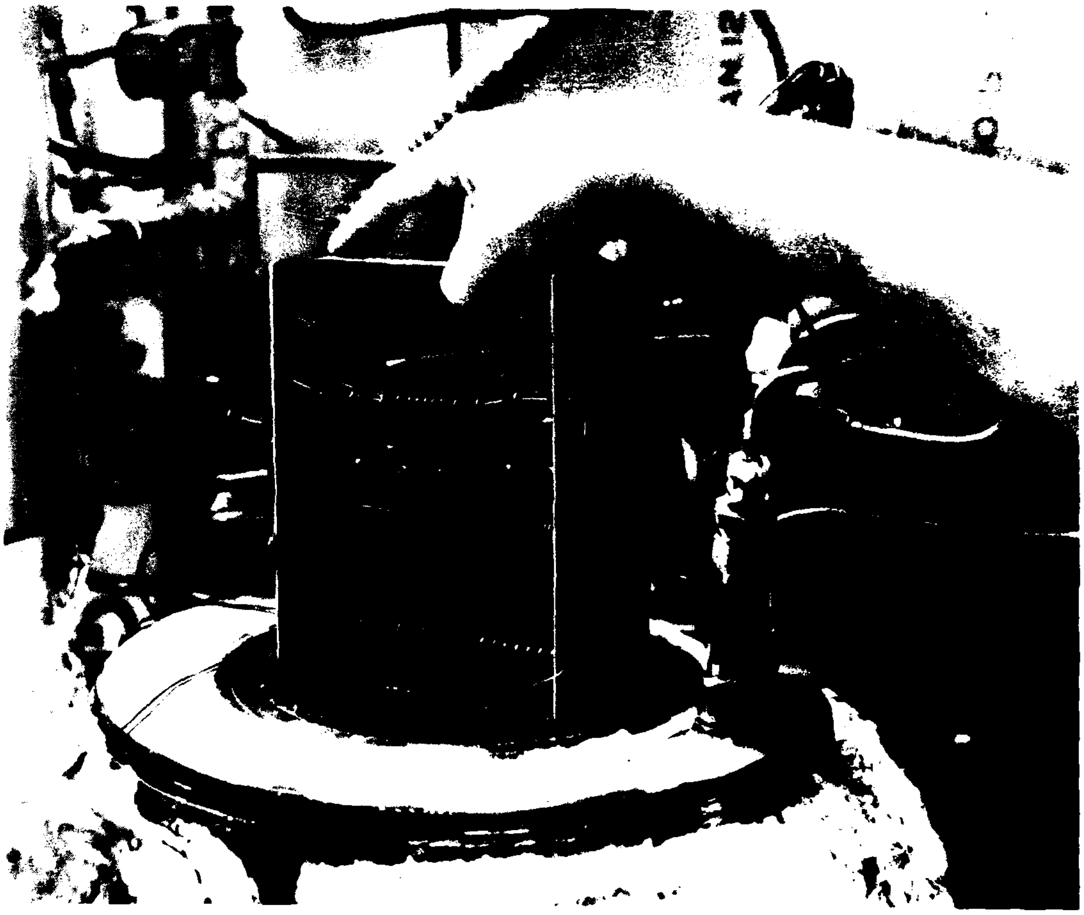


FIGURE 6.—SPECIMEN LOADING OF FLIGHT CYCLE CHAMBER

2.1.2 Accelerated Cycle

The accelerated cycle, figure 7, exposes the specimens to a minimum of 140 hr per week of elevated-temperature fuel vapor. The exposure chamber is shown in figure 8 with the test specimens in place.

2.1.3 Test Tank Cycles

Environmental exposure cycling of the tanks is the same as for the accelerated cycle except that nitrogen at atmospheric pressure is substituted for air at 1 psia. The tank is not designed to withstand the near-vacuum pressure.

2.1.4 Special Environmental Cycles

Another set of environments was employed to determine the possibility of future problems in a short time. The environments were not representative of any set of conditions the sealant could be expected to encounter, but combined all the factors not yet investigated that were suspected to degrade the sealant. All of them used fuel saturated with water. They were:

(A) Specimens exposed to liquid fuel which was recycled in a 450° F chamber with an air bleed at pressure equivalent to 55,000- to 62,000-ft altitude.

(B) Specimens exposed to 160° F fuel and an air bleed at pressure equivalent to 18,000-ft altitude for 3 days followed by fuel vapor at 450° F, recycled fuel, and an air bleed at an equivalent pressure of 55,000- to 62,000-ft altitude for 4 days.

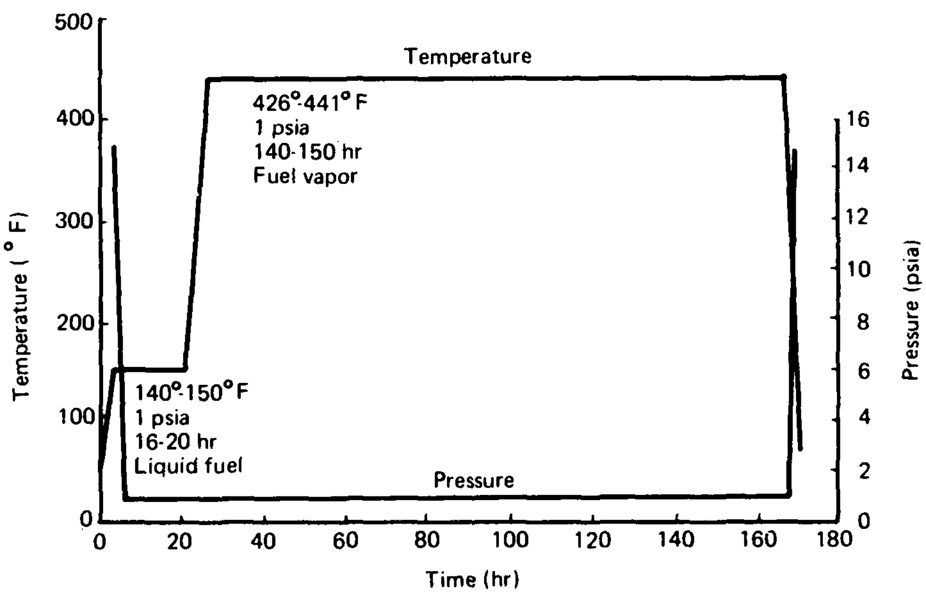


FIGURE 7.—ACCELERATED EXPOSURE CYCLE

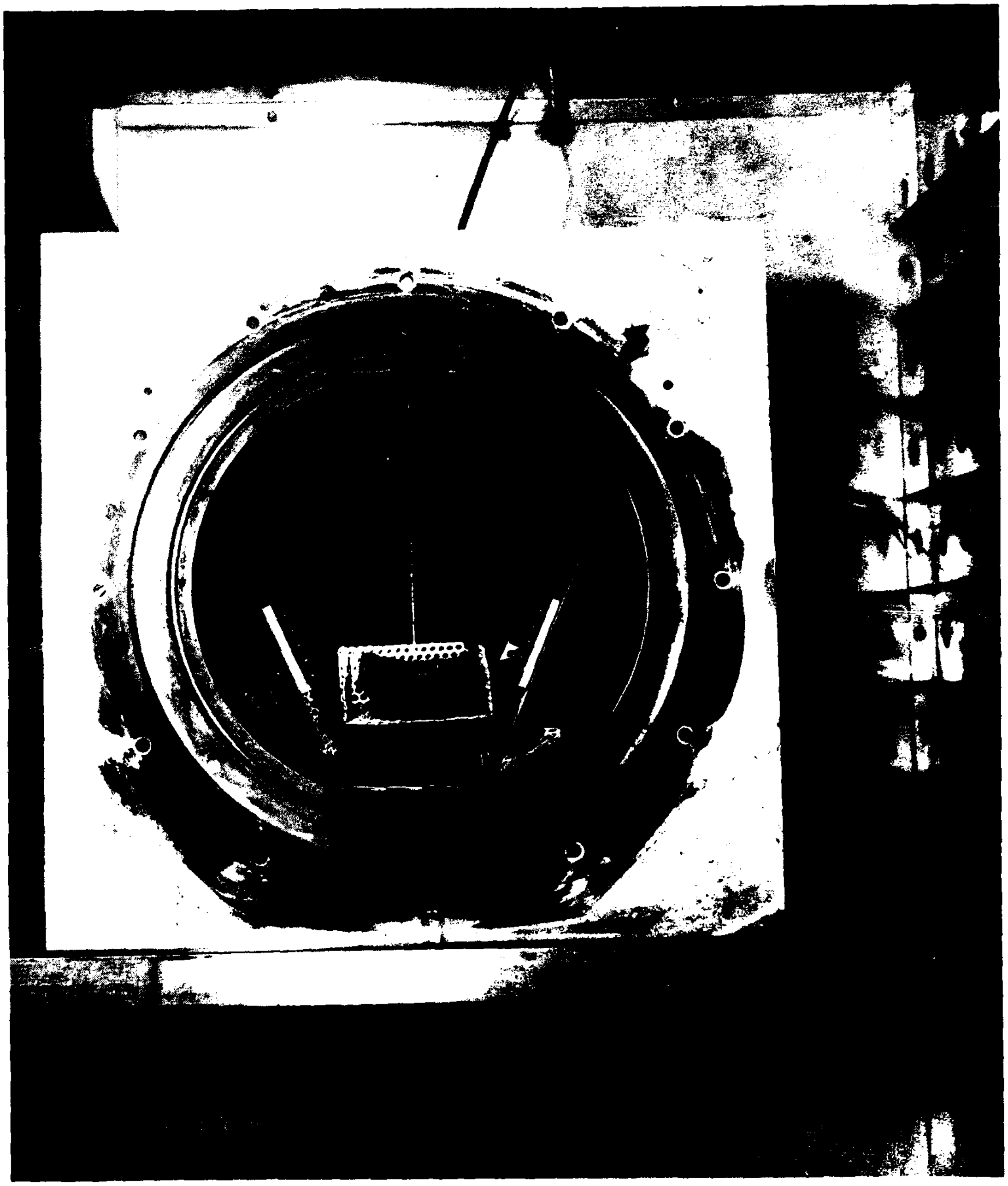


FIGURE 8.–ACCELERATED CYCLE EXPOSURE CHAMBER

(C) Same as (B) except 3% salt water solution in the fuel at a ratio of one part salt water to 10 parts fuel.

(D) Same as the 4-day phase of (B).

2.2 PREPARATION OF TEST SPECIMENS

2.2.1 Cleaning of Test Panels

All test panels and parts were cleaned by applying cleaner from clean polyethylene (or equivalent) squeeze bottles. The cleaner consisted of:

	Volume Percent
Aromatic naphtha (TT-N-97, type I, grade B)	50
Ethyl acetate (TT-E-751) or isopropyl acetate (TT-I-721)	20
Methyl ethyl ketone (TT-M-261)	20
Isopropyl alcohol (MIL-F-5566)	10

The cleaner was applied directly from the bottle to the panel or part so that the entire surface was wetted. The surfaces to be cleaned were thoroughly scrubbed with clean gauze pads wetted with cleaner. The solvent was wiped off while wet with clean, dry gauze pads. This procedure was repeated as required to produce a clean surface. Each gauze pad was used for one scrubbing or drying application only. Cleaned panels were not stacked, but were covered with paper toweling or equivalent until used. Test panels and parts were used within 8 hr after cleaning.

2.2.2 Application of Primer

A coat of primer was applied to cleaned test panels before applying the sealant. The primer was applied in a continuous coat and as uniformly as possible using a gauze pad. The primed panels were dried for 30 ±10min at 75° ±5° F and 50% ±5% relative humidity and then immediately placed in an oven and the primer cured at 450° F for 25 ±5 min. After curing, the primed surfaces were protected from contamination until sealant application. If sealant was not applied within 90 min after the primer cure, the panels were cleaned and reprimed.

2.2.3 Preparation of Sealant

Prior to mixing, two-component sealant compounds were stored at 75° ±5° F for a sufficient time to allow the material to reach a state of equilibrium with that temperature. The activator was added immediately before weighing. Mixing instructions were as follows:

(A) Weigh the correct amounts of base and activator onto a clean, flat stainless steel plate or pan immediately prior to mixing. The activator must not be allowed to contact the plate.

(B) Handmix the sealant compound by folding and squeezing with a spatula for a minimum of 5 min until the sealant compound appears uniform.

(C) Spread the sealant compound on a clean, flat stainless steel plate or pan so that the maximum depth is less than 1/2 in. Vacuum degas the sealant compound for 10 min at 0.25 psia or more.

(D) Remove the plunger and plug the nozzle end of a cartridge for the Semco 250 gun. Scoop up the sealant with a spatula, place in the open end of the cartridge, and drive down by sharply rapping the nozzle end of the cartridge on something solid. Repeat until the cartridge is filled.

(E) Vacuum degas the filled cartridge for 5 min or more at 0.25 psia. Use a plastic film as necessary as an extension of the cartridge to prevent overflow of the sealant. Place the plunger in the cartridge using care to minimize air entrapment.

When required, the sealant was put into refrigerated storage at or below -40° F immediately after being placed into the cartridges. In no case was "dry ice" used for refrigeration. The sealant was stored at or below -40° F for a minimum of 16 hr but not longer than 72 hr and conditioned at 40° ±5° F for 4 ±2 hr immediately prior to thawing. It was thawed by vertically immersing the frozen cartridges in a 120° ±2° F water bath for 4 min ±5 sec with the plugs installed and the upper end of the cartridge 1 in. above the liquid level.

2.2.4 Sealant Cure

Standard cure was 14 consecutive days at 75° ±5° F and 50% ±5% relative humidity. An accelerated cure consisting of 24 hr (minimum) at 160° ±10° F followed by 1 hr (minimum) at 300° ±10° F was sometimes used instead of the standard cure.

2.2.5 Preparation of Sealant Slabs

The sealant was cast to a thickness of 0.125 ±0.008 in. in a closed mold lined with Teflon. The mold was filled by extruding the sealant from a sealant gun with a Semco 440 nozzle. The nozzle was freed of air by a preliminary extrusion of 2 to 3 in. of sealant. During the casting operation, the tip of the nozzle was placed in an injection mold and was not removed until the mold was filled to excess.

When the standard cure was used, the sealant was kept in the closed mold until the cure was completed or removed at any time after 96 hr. When the accelerated cure was used, the sealant was allowed to remain in the mold at 75° ±5° F and 50% ±5% relative humidity for a minimum of 48 hr prior to the 160° F exposure. The slabs were removed from the mold before completing the cure at 400° F.

2.3 TEST PROCEDURES

2.3.1 Physical and Mechanical Properties

2.3.1.1 Tensile Strength and Elongation

Ultimate tensile strength and elongation were determined in accordance with ASTM D-412 using a jaw separation rate of 20 in./min. Miniature specimens were used cut from slabs prepared as described in section 2.2.5. Four specimens were tested for each point.

2.3.1.2 Hardness

Type A durometer hardness was determined in accordance with ASTM D-2240 taking the median value as the hardness for each specimen. The hardness is reported as the average of four specimens. Volume change specimens were used for hardness measurements.

2.3.1.3 Weight Loss

Specimens approximately 1 by 2 in. were cut from a slab of sealant prepared in accordance with section 2.2. Before and after the applicable environmental exposure period, the test specimens were conditioned for 24 hr in a dessicator, then weighed immediately.

Percentage weight loss was calculated as follows:

$$\frac{(W_1 - W_2) \times 100}{W_1}$$

Where

W_1 = weight of sample before aging
W_2 = weight of sample after aging

Percentage weight loss for each determination is the average of four specimens.

2.3.1.4 Volume Change

Specimens approximately 1 by 2 in. were cut from a slab of sealant prepared in accordance with section 2.2. The volume change of environmentally aged specimens was determined in accordance with ASTM D-471. Volume change is reported as the average of four specimens.

2.3.1.5 Adhesion to Titanium (Tee Peel)

(A) Details of specimen preparation

The required number of 0.05- by 2.9- by 6-in. panels were prepared from annealed 6Al-4V titanium alloy.

An equal number of 2.9- by 12-in. strips were prepared from 200-mesh stainless steel screen.

The panel surfaces and screen were cleaned as described in section 2.2.1 and primer was applied as in section 2.2.2.

The sealant was applied to approximately 5 in. at one end of the panel to a depth of 0.125 ±0.025 in. and level, using a suitable jig as shown in figure 9. The screen was impregnated with sealant for approximately 5 in. on one end. The sealant-impregnated end of the screen was placed on the panel so that the loose, unimpregnated end faced the end of the panel free from sealant. The screen was smoothed down on the layer of sealant, taking care not to trap air under the screen. An additional 0.125 ±0.025 in. coating of sealant compound was applied over the impregnated screen. The sealant was cured in accordance with section 2.2.3.

(B) Testing of specimens

After exposure, two 1-in.-wide strips were prepared on each panel by cutting completely through the screen and sealant to the metal lengthwise along the panel and continuing completely along the unimpregnated screen. The loose end of each 1-in.-wide strip in turn was clamped in one jaw of a suitable recording tensile testing machine, and the adjacent end of the panel was fastened in the other jaw as shown in figure 10. Cuts through the sealant under the screen were made so that an initial separation of sealant from the metal panel was promoted. The screen was pulled at an angle of 180° from the panel and at a jaw separation rate of 2 in./min.

Cuts in the sealant to the metal panel at the junction of separation were made at an angle of 45° toward the direction of separation at approximately 0.4-in. increments (approximately every 24 sec) on the left side of the panel as shown in figure 10. No cuts were required for 100% adhesive failure; however, any cohesive failures were treated as above. On the right side, except for the initial cut to promote separation, cuts were made only as necessary to prevent the sealant from peeling from the screen. All cuts extended completely across the strip being peeled and penetrated completely through the sealant to the panel.

The percentage of cohesive separation was determined from the ratio of cohesive separation area to total cohesive and adhesive separation on both test areas. The cohesive strength was determined during cohesive tear. The average of the cohesive strength, as determined from an extensiometer graph of the right side pull, was recorded. Values recorded during cutting, or while load was being picked up after cutting, were not included in the average. Panels which were environmentally exposed were tested within 24 hr after removal from the exposure condition.

2.3.1.6 Adhesion to Titanium (Fillet Peel)

A tab of annealed titanium 6Al-4V alloy approximately 1 by 2 in. was prepared for application of sealant according to sections 2.2.1 and 2.2.2, and a fillet of sealant was applied down the centerline and cured. Testing was done by cutting through the sealant to the titanium and attempting to free the sealant from the titanium by lifting or picking. It was observed whether the failure was adhesive or cohesive.

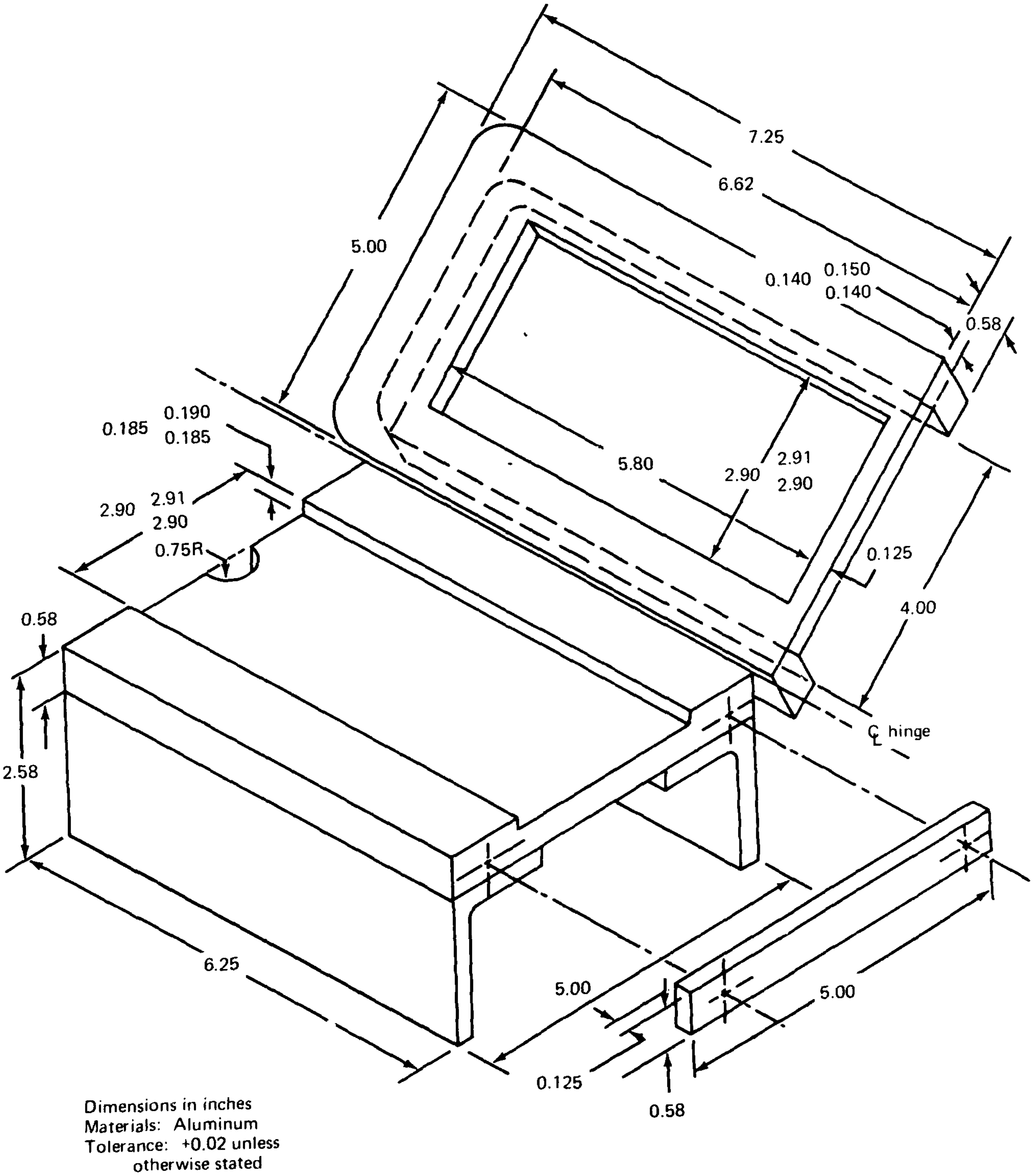


FIGURE 9.—PEEL PANEL JIG

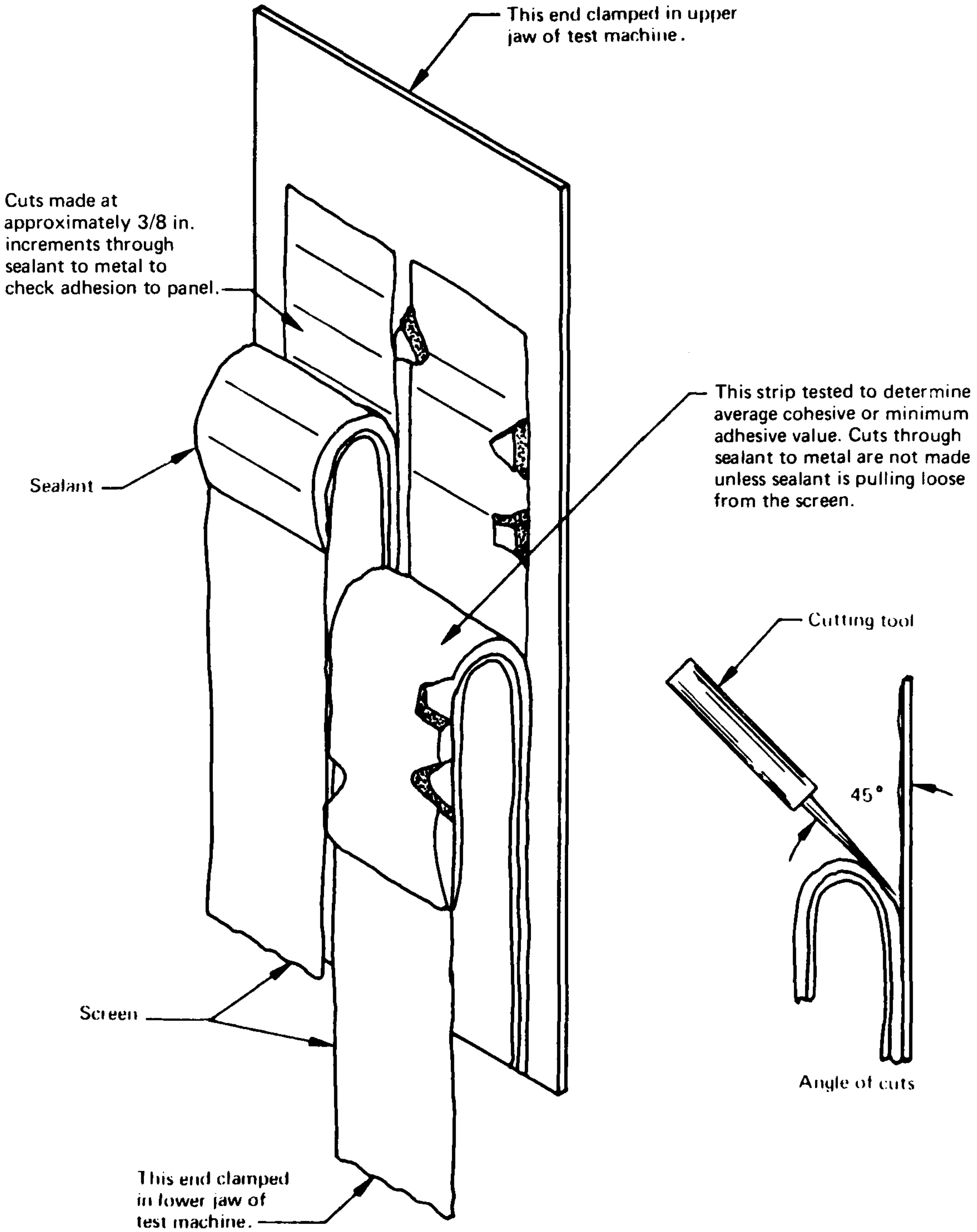


FIGURE 10.—PEEL STRENGTH TESTING

2.3.1.7 Adhesion to Materials Other Than Titanium

Tee peel and fillet peel specimens were prepared and tested as in sections 2.3.1.5 and 2.3.1.6, except that surface treatments were varied depending on the material. Each material and treatment is described in section 3.3.

2.3.1.8 Compatibility With Aircraft and Manufacturing Fluids

Test specimens were exposed to fluids and environments expected for the particular situation. Instructions in each case were as follows:

(A) Fuel (ASTM D-1655 Jet A), hydraulic fluid (Humble WS7597M), engine lubricant (Texaco SATO 7730), heat transfer fluid (Dow Corning 331), shock strut fluid (Mobil RM 184A), and deicing fluid (MIL-A-8243 type C), a mixture of 90% fuel and 10% hydraulic fluid and a mixture of 10% shock strut fluid and 90% fuel.

(1) Expose specimens to environmental cycling consisting of a 1-hr immersion in the test fluid at 160° F, followed by 2 hr at 450° F and 1 psia. Allow excess fluid to drain from the specimens prior to the 450° F exposures.

(2) Test exposed specimens at the end of 10 cycles.

(3) For controls, test unexposed specimens and specimens exposed to heat only, as well as the specimens immersed in fuel during environmental cycling.

(B) *Anti-icing fluid (Phillips PFA 55MB)*

(1) Prepare eight sets of specimens. Prepare six titanium stress corrosion (double U-bend) specimens.

(2) Prepare two test fluids as follows:

(a) Test fluid 1 (control fluid)–50% fuel and 50% water

(b) Test fluid 2–50% fuel, 25% water, and 25% Phillips PFA 55MB fuel additive

(3) Test one set of specimens from each test fluid after the following exposure:

(a) 10 days in the fuel layer

(b) 10 days in the aqueous layer

(c) 3 days in the fuel layer followed by 7 days at 450° F

(d) 3 days in the aqueous layer followed by 7 days at 450° F

Maintain the test fluids at 140°-180° F. Replace the fluids at intervals during the immersion exposure, dependent on the supply of fuel additive.

(4) Immerse three double U-bend titanium specimens at the aqueous/fuel interface in each test fluid for 3 days followed by 7 days at 450° F. Exposure of these specimens shall be concurrent with the exposure in 3c and 3d above.

(C) Leak detection materials

Materials from three different leak detection methods were used. Tensile strength, elongation, and hardness were measured after exposure for 24 hr in the fluid, followed by 168 hr at 450° F in air. This was repeated with a 30-sec spray wash following the 24-hr immersion. Control specimens for comparison were tested after exposure for 24 hr in fuel, both plain and dyed, followed by 168 hr at 450° F in air. The dyed fuel contained 0.1 g of dye per 200 ml of fuel. Leak detection fluids examined were:

(1) Snoop

(2) Tereco indicator paint

(3) Tereco car shampoo

(4) Fuller O'Brien indicator paint

(5) An ammonia-air mixture at 5 psi containing 12% ammonia

(6) DuPont oil red organic dye

(D) Cutting fluids (TB-1, water)

The titanium surface was cleaned according to section 2.2.1, except that the cutting fluid was substituted for the cleaner solution. Some panels were then primed (section 2.2.2) without recleaning and some were recleaned. Fillet peel specimens were made according to section 2.3.1.6, exposed to five accelerated cycles and tested.

(E) Water–filleting sealant

Nine fillet peel specimens were prepared and tested according to the following instructions:

(1) Evaluate initial adhesion on three specimens (controls) and retain.

(2) Immerse the remaining specimens in the water phase of a fuel/water mixture and maintain at room temperature for 336 hr (2 weeks).

(3) Place the specimens in water only, lower the pressure to 1 psia, and raise the temperature to the boiling point. Hold for a minimum of 2 hr and boil to dryness.

(4) Evaluate three specimens for adhesion. If results are satisfactory, expose the three remaining specimens and the controls to one accelerated fuel/heat cycle, and evaluate for adhesion.

2.3.1.9 Titanium Compatibility (Stress Corrosion)

A titanium compatibility test uses three double specimen setups (each containing one "inner" and one "outer" specimen strip) contaminated with the material under test, and one control double specimen prepared and tested similarly but not contaminated with the material under test. Procedure is as follows:

(A) Prepare 0.75 by 3 (grain direction) by 0.050 ±0.003 in. inner and outer specimen strips, having surface finish 20 RHR or more, from annealed 6Al-4V titanium sheet and hole-punch each strip on the centerline as shown in figure 11. Brake-form each specimen strip over the requisite size mandrel in one pass to produce an unrestrained angle of 65° ±5°. Use a 0.28-in.-radius mandrel for the outer strip and a 0.22-in.-radius mandrel for the inner strip.

Part name	A	Hole size	Forming mandrel radius
Outer strip	0.50	0.28	0.28
Inner strip	0.55	0.31	0.22

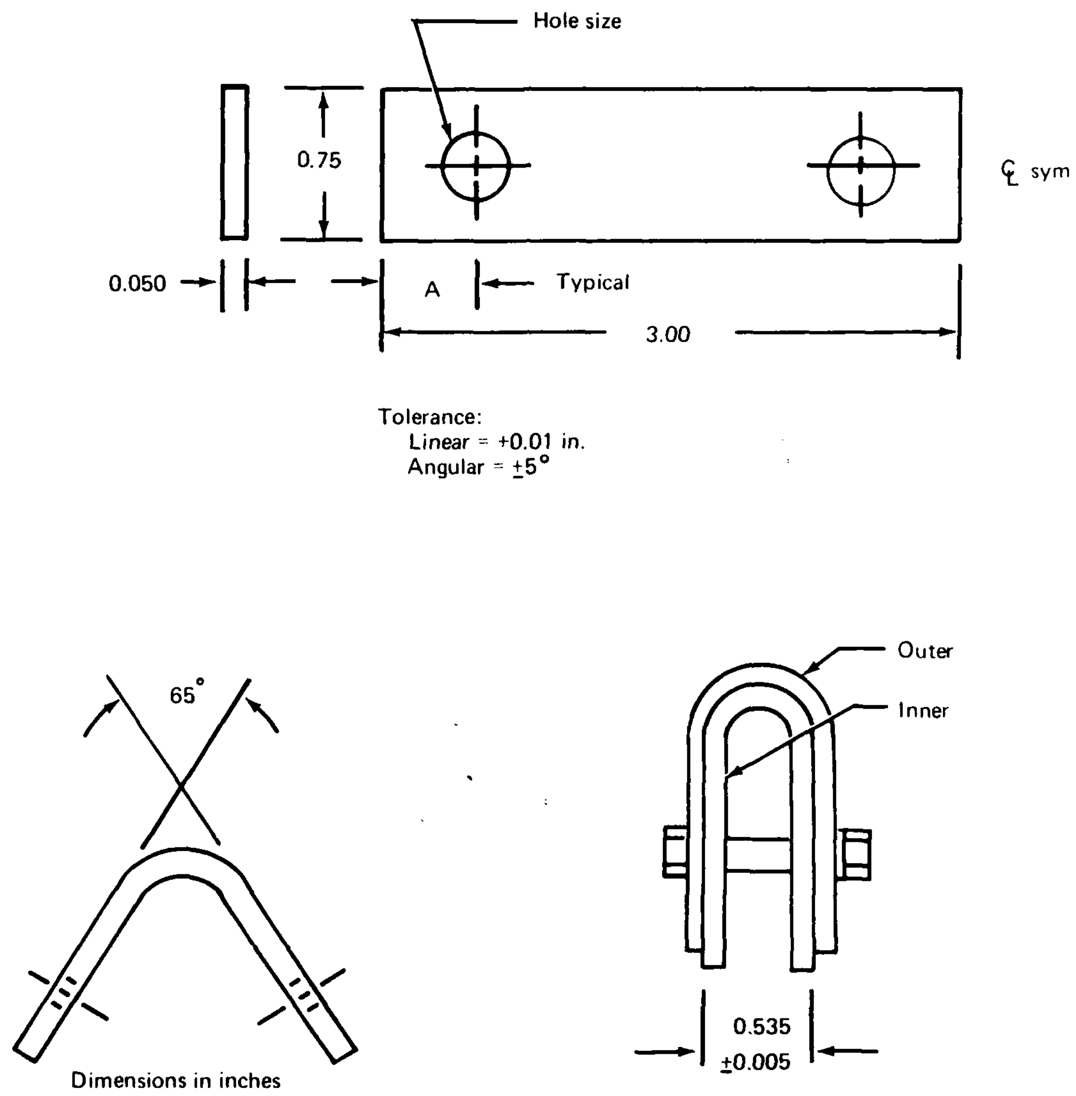


FIGURE 11.--TITANIUM STRESS CORROSION SPECIMEN FABRICATION

(B) Thoroughly clean one inner and one outer specimen strip by solvent and alkaline degreasing followed by etching in accordance with step D1 below for 2 to 3 min. Apply the sealant system to the inner specimen to cover especially the area between the strips. Assemble the inner and outer bent strips to form a double specimen. Align the strips by inserting a clean, bare steel 3/16-in. OD rod through the holes, then load the specimen in a vise until the rod can be removed and replaced with a clean, unplated, corrosion-resistant steel (or low-alloy steel) 1/4-in. OD bolt. Insert bolt, then continue loading the specimen until the sides of the outer specimen strips are 0.65 ±0.005 in. apart. Do not contaminate or overload the double specimen. Prepare two double specimens as in A and B above, plus one control double specimen.

As an optional method for closer fit between inner and outer specimen strips, place the double specimen with bent end down on a wad of clean cheesecloth. Strike the inner specimen with a hammer to force it closer (or rigid) to the outer specimen strip.

(C) Expose the double specimens, and the control specimen, for 168 hr at 500° ±50° F in an electrically heated air furnace.

(D) After the specimens have cooled, remove the bolts and clean each exposed specimen strip as follows:

(1) Soak 30 min in 100 oz/gal (i.e., 50% by weight) NaOH at 280° F

(2) Rinse

(3) Etch 3 to 4 min in 45 oz/gal HNO_3 and 4 oz/gal HF (i.e., 40% by volume of 40° to 42° Baume HNO_3 and 3.5% by volume of 70% HF solution) at room temperature

(4) Rinse thoroughly and dry.

(E) Visually inspect the two parts of each specimen at 4X-10X magnification for evidence of attack. Reject the test material if either the inner or outer specimen strip shows pitting, cracking, or rough etching (i.e., areas with ridges or areas rougher than 32 RHR). Staining, shadowing, or frosting do not constitute failure if the surfaces remain smoother than 32 RHR.

2.3.1.10 Reversion Resistance

Two types of tests were conducted:

(A) Reversion tube test

Tubes of lengths between 3 and 24 in. with various inside diameters were filled with sealant. They were either exposed to 450° F in air for 2 hr followed by 1 week in the accelerated cycle, or for 3 days at 450° F. They were observed for extrusion and tearing, then sectioned through the center to observe any sign of reversion.

(B) Extrusion block test

The extrusion block has grooves of different sizes and shapes covered with a removable plate which extends beyond the block sufficiently to allow for a fillet of sealant to cover the openings. The grooves of the blocks were injected with sealant; in some instances a fillet was applied. They were cured and exposed to environments described in section 3.7. They were then examined for extrusion and tearing of the sealant and rupturing of the fillet. The cover plate was removed to observe any sign of reversion.

2.3.2 Functional Testing

2.3.2.1 Picture Frame Shear

(A) Details of specimen preparation

The test panel was cleaned and primed as described. For a faying surface sealed panel, a layer of sealant was applied to one of the mating surfaces and the panel assembled while the sealant was still wet so that a continuous bead was extruded. The extruded sealant was then removed. Sealant was applied to fillet-sealed panels after assembly. A continuous fillet was applied around the periphery of the joint. Curing was in accordance with section 2.2.4.

(B) Testing of specimens

Leak testing was accomplished by placing a plexiglass box over the T side of the panel (see figure 12), filling the box with water and pulling a 2.0-psig vacuum. Leakage was detected by observing the formation of bubbles. The test panel was then assembled in a picture frame fixture for application of structural loads. The frame was placed in an insulated conditioning chamber and loaded from the corners. The test apparatus is shown in figure 13. A 50,000-lb tension load was applied to the frame 10 times at -50°F, 10 times at room temperature, and 10 times at 450°F. A hydraulic cylinder was used for load application. The 50,000-lb load represents 100% of design limit load for the test panel.

After loading, the test panel was tested for leaks as described above. The panel was then subjected to environmental aging. After various periods of aging, the panel was subjected to the loading and leak-testing conditions described above.

2.3.2.2 Sustained Fillet Deflection

A 3-in.-wide flat sheet of annealed 6Al-4V titanium alloy was fitted with various width strips of annealed 6Al-4V titanium running laterally to the sheet and riveted at the center. When curved as shown in figure 14, the strips were separated from the sheet at their edges by various amounts depending upon their widths. The gaps were measured and ranged from 0.005 to 0.1 in. The sheet was then allowed to return to the flattened condition, was treated in accordance with sections 2.2.1 and 2.2.2, and fillets of sealant were applied and cured at the mating surface edges. The assembly was then mounted in a jig that held it in the curved condition and was exposed to accelerated cycle exposure, flight cycle exposure, and circulating air at room temperature, 400°F, and 450°F. The fillets were examined periodically for signs of splitting.

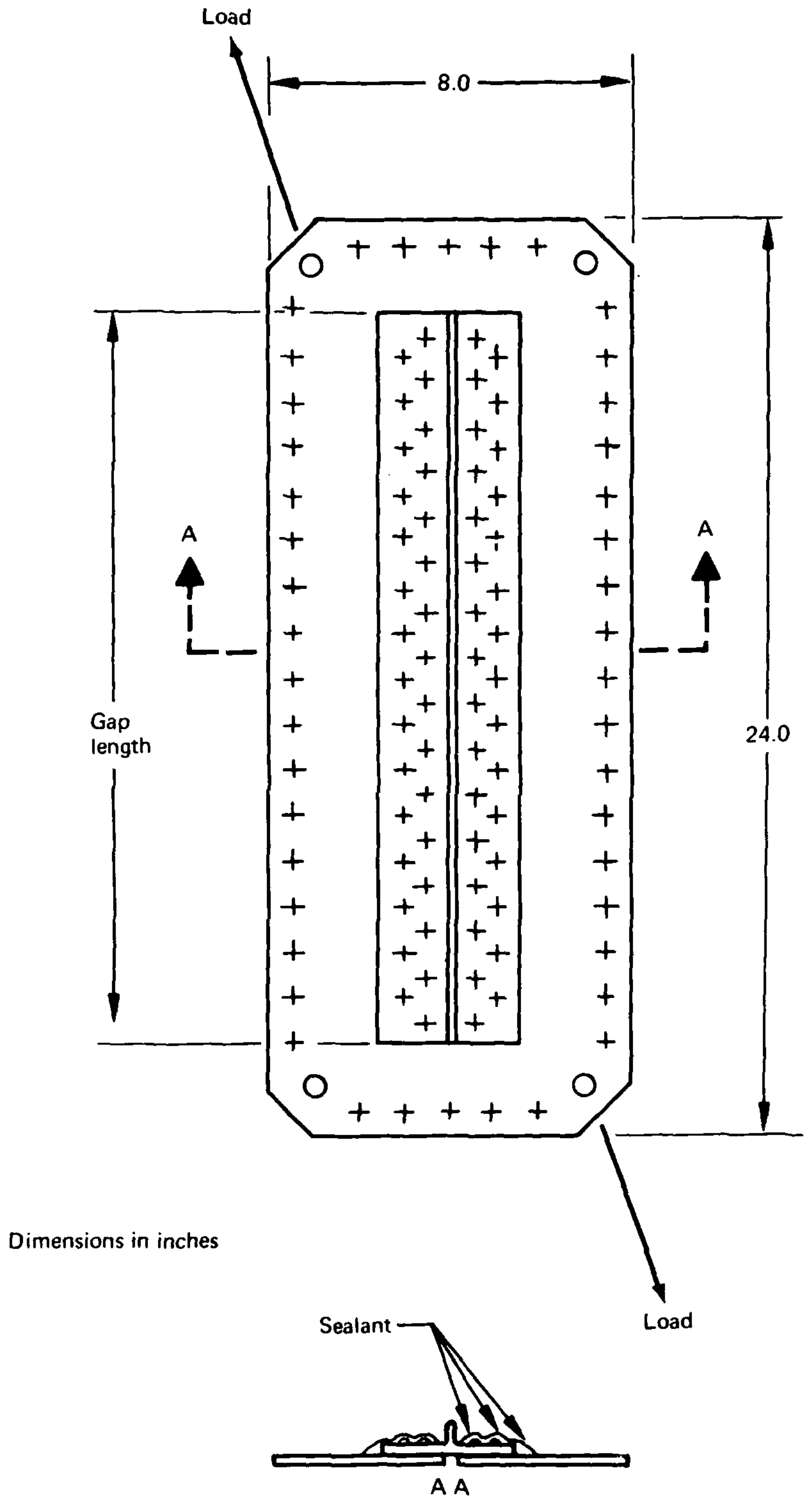


FIGURE 12.–PICTURE FRAME SHEAR SPECIMEN

FIGURE 13.—PICTURE FRAME TEST FIXTURE

2.3.2.3 Cycling Fillet Deflections

Two types of cycling fillet deflections were used:

(A) Deflection simulator

Two 0.125- by 0.75- by 1.5-in. annealed 6Al-4V titanium alloy tabs were prepared according to sections 2.2.1 and 2.2.2. They were supported so that the ends overlapped as shown in figure 15, and a fillet of sealant was applied. After cure, each was mounted in a dynamic test machine designed to cause the tabs to separate at the overlap at a rate of 70 cycles per minute and enable operation between -100° and 500° F. The gap was adjustable between 0.001 and 0.03 in. Separation caused the fillet to tear at the throat. The length of the tear was measured after various numbers of cycles.

(B) Flight cycle deflection

Specimens were prepared from annealed 6Al-4V titanium alloy as shown in figure 16. They were cleaned and primed prior to fillet application according to sections 2.2.1 and 2.2.2. The titanium strip, B, was of constant length. Strip A was varied in length so that the gap between A and B at the end of A could be varied with a constant deflection of B. Six such specimens were mounted in a vertical row and fitted to the interior of the lid of the flight cycle apparatus. The end of each of the B strips was deflected at a rate of approximately 2 cycles per minute by means of a rod extending through the lid. The length of tear in each fillet throat was measured each time the flight cycle chamber was opened.

2.3.2.4 Blowout Resistance

An annealed 6Al-4V titanium alloy plate containing holes of 0.25, 0.20, 0.15, 0.10, and 0.05 in. was prepared according to sections 2.2.1 and 2.2.2, and fillets were applied over the holes. Dimensions of the fillets were as required by the application document, XBAC 5533 (0.25 and 0.125 in. thick). The plate was attached as a cover of a closed box with the fillets on the outside. The box was then pressurized at 450° F.

2.3.2.5 Repairability

(A) Fillet peel tests as described in section 2.3.1.6 were conducted with specimens prepared using two layers of sealant. The layer next to the metal was allowed to cure for various lengths of time. The second layer was applied while the first was still tacky. Specimens were tested after complete cure and after three accelerated exposure cycles. The time at which the lower layer became tack free was also determined.

(B) Tee peel specimens were prepared as in section 2.3.1.5, and the lower layer was allowed to cure for 30 min less than the tack-free time determined by procedure A above before application of the second layer and the wire. The specimens were cured, peeled half way, and placed into accelerated cycling exposure. They were tested periodically after exposure.

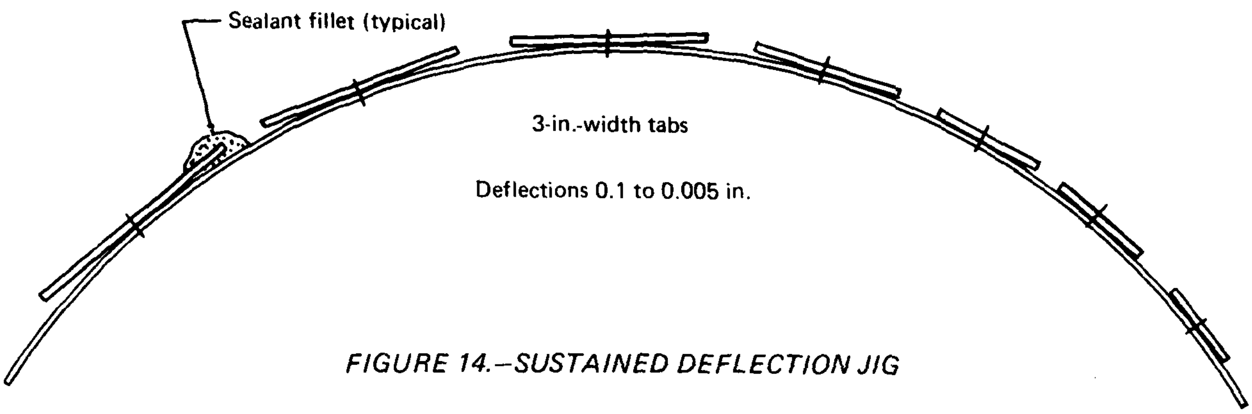


FIGURE 14.–SUSTAINED DEFLECTION JIG

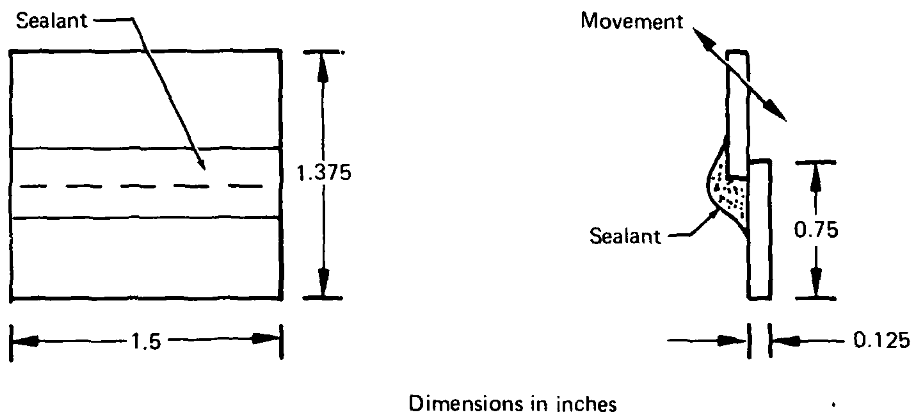


FIGURE 15.–DEFLECTION SIMULATOR SPECIMEN

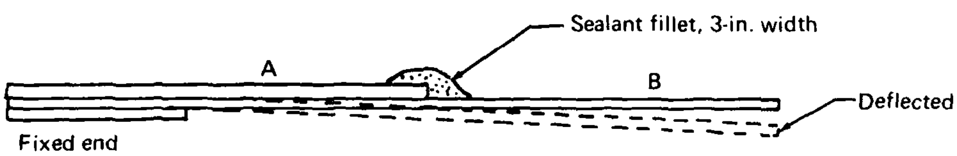


FIGURE 16.–FLIGHT CYCLE DEFLECTION SPECIMEN

(C) Tee peel specimens were prepared and processed as in procedure B above, except that the lower layer was allowed to cure and was scrubbed vigorously with cheesecloth until all gloss was removed before application of the second layer.

(D) Procedure C was followed except that a coupling agent was applied to the lower surface before the second layer was applied.

(E) Specimens were prepared and tested as in B above except that, after the lower layer had cured, the specimens were exposed to one accelerated cycle followed by immersion in ASTM D-1655 jet A fuel at room temperature for 168 hr. The specimens were then dried according to the schedule below to drive off the fuel.

(1) 200° ±25° F for 45 $^{+5}_{-0}$ min

(2) 250° ±25° F for 45 $^{+5}_{-0}$ min

(3) 300° ±25° F for 45 $^{+5}_{-0}$ min

(4) 350° ±25° F for 6 hr $^{+15}_{-0}$ min

The surfaces were then scrubbed vigorously with cheesecloth soaked with the solvent of section 2.2.1. The solvent was allowed to remain in contact with the surface for 30 min, then was wiped away with dry cheesecloth before application of the second layer.

(F) Procedure E was followed except that a coupling agent was used before application of the second layer.

2.3.3 Qualification Tests

Testing of sealants to the requirements of the purchase control specification XBMS 5-50 had begun. Tests are described in the appended specification.

2.3.4 Tank Tests

The tank tests were performed by the Wichita Division of The Boeing Company. A complete description of tanks, facilities, tests, and results is appended as a separate report, D3-8297.

3.0 RESULTS

The test results presented here are from a number of different lots of Dow Corning fluorosilicone sealant and one sample of the Viton 487-based material furnished by the Air Force Materials Laboratory.

The early lots of the fluorosilicone were designated by a production number, DC 94-516. Though the basic polymer was not being changed, improvements in processing were resulting in better properties in each succeeding lot. Because of this, Boeing and Dow Corning agreed to change to an experimental designation, DC 77-028, until optimization had been reached. The basic DC 77-028 material was further modified to make it more usable as a faying surface sealant (designated DC 77-053), and an injection sealant (designated DC 77-066). The last received lot of DC 77-028 material, 401117, was 500 lb to demonstrate Dow Corning's ability to supply production quantities.

The Viton-based material from the Air Force Materials Laboratory, designated as AFML 397, was furnished as a molded slab from which specimens were removed for test.

Unless otherwise noted, five specimens were tested per point.

3.1 TENSILE STRENGTH, ELONGATION, HARDNESS, VOLUME CHANGE, WEIGHT CHANGE, AND PEEL STRENGTH

The test results of the effects of accelerated cycling on properties at -50° F, room temperature, and 450° F are plotted and tabulated for each of three lots of fluorosilicone and one lot of fluorocarbon (AFML 397) in figures 17 through 28. Effects of flight cycling are shown in figures 29 through 35. Also shown on the charts is the position at the time of SST termination. Since the most severe environment of either cycle is the high temperature-fuel vapor phase, time at that condition was used as a baseline so that effects of the two cycling environments could be compared. In all cases there was a rapid deterioration of properties in the first few hundred hours, then a leveling off. The tensile strength and elongation appeared to have stabilized at about 285 psi and 95%, respectively, at room temperature. When exposure and testing resumed after the SST termination, the last of the specimens from one lot of sealant, 206177, gave tensile strength and elongation values below the stable level. This occurred after 9996 hr exposure to fuel vapor and 426° to 441° F in the accelerated cycle. Specimens from another lot, 1222, exhibited no change after 7675, 9036, and 11,427 hr of the same exposure.

Two sets of specimens were subjected to the special environmental cycling. Results are in tables 1 and 2. The sealant was not seriously affected.

3.2 ADHESION TO TITANIUM

Concern caused by the poor and inconsistent adhesion prompted a concentrated effort by Dow Corning to develop a more dependable primer with less sensitivity to ambient conditions and thickness variations. Thirteen primers had been tested by Boeing using the fillet peel test at the time of the SST contract termination; none of them exhibited any superiority over the customarily used primer, DC 77-037.

	Hours of exposure at 426°–441° F in fuel vapor							
	0	528	1026	1456	2593	3566	5322	9966
Shore A Hardness	37	48	43	46	43	42	–	40
Peel (ppi/% coh)	Invalid tests							
Weight change (%)		-5.6	-3.5	-3.6	-3.8	-5.0	–	-9.8
Volume change (%)		4.5	-5.2	-5.0	-5.5	-6.7	–	-11.8

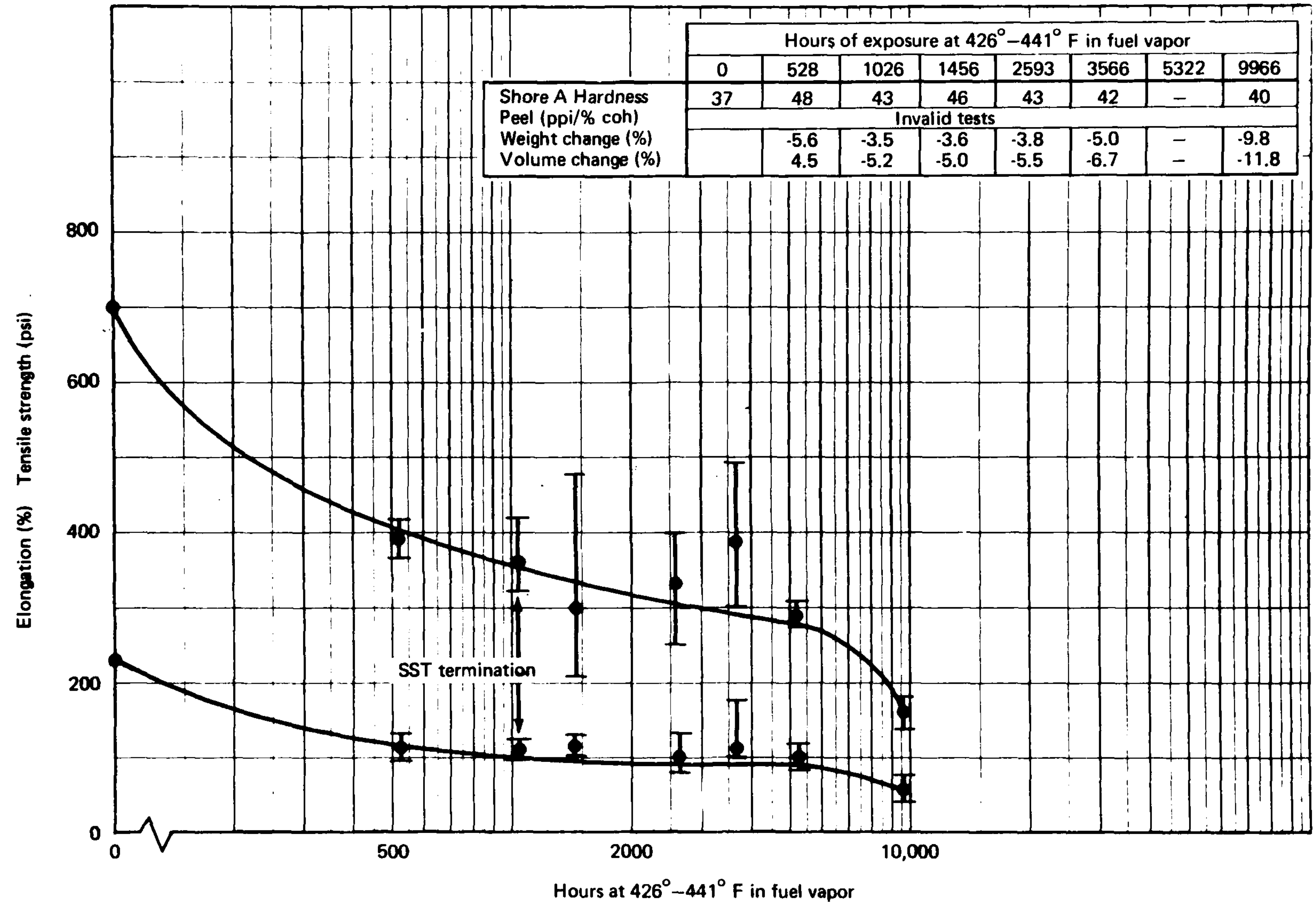


FIGURE 17.–ACCELERATED CYCLE EXPOSURE OF DC 77-028, LOT 206177, TESTED AT ROOM TEMPERATURE

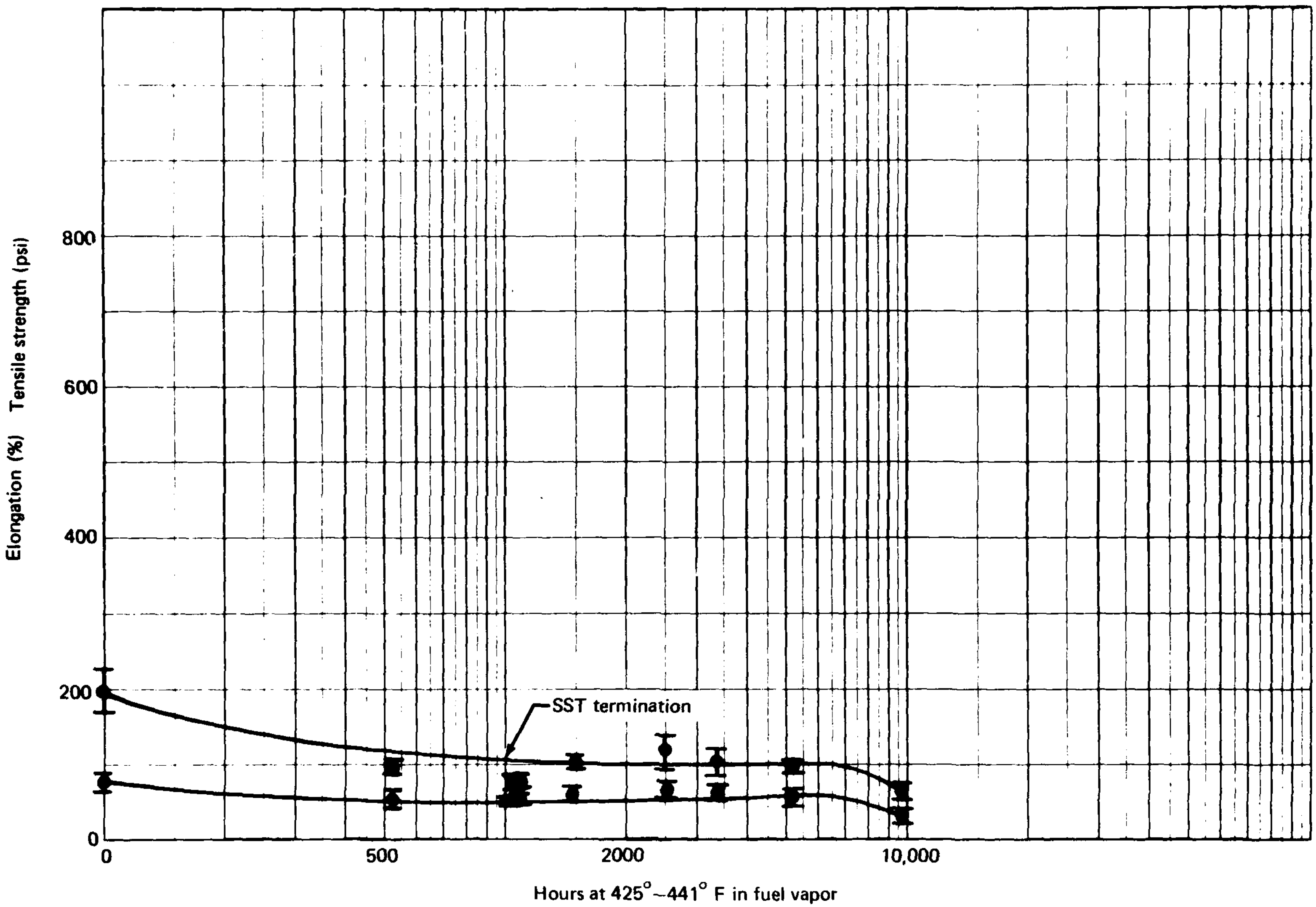


FIGURE 18.—ACCELERATED CYCLE EXPOSURE OF DC 77-028, LOT 206177, TESTED AT 450° F

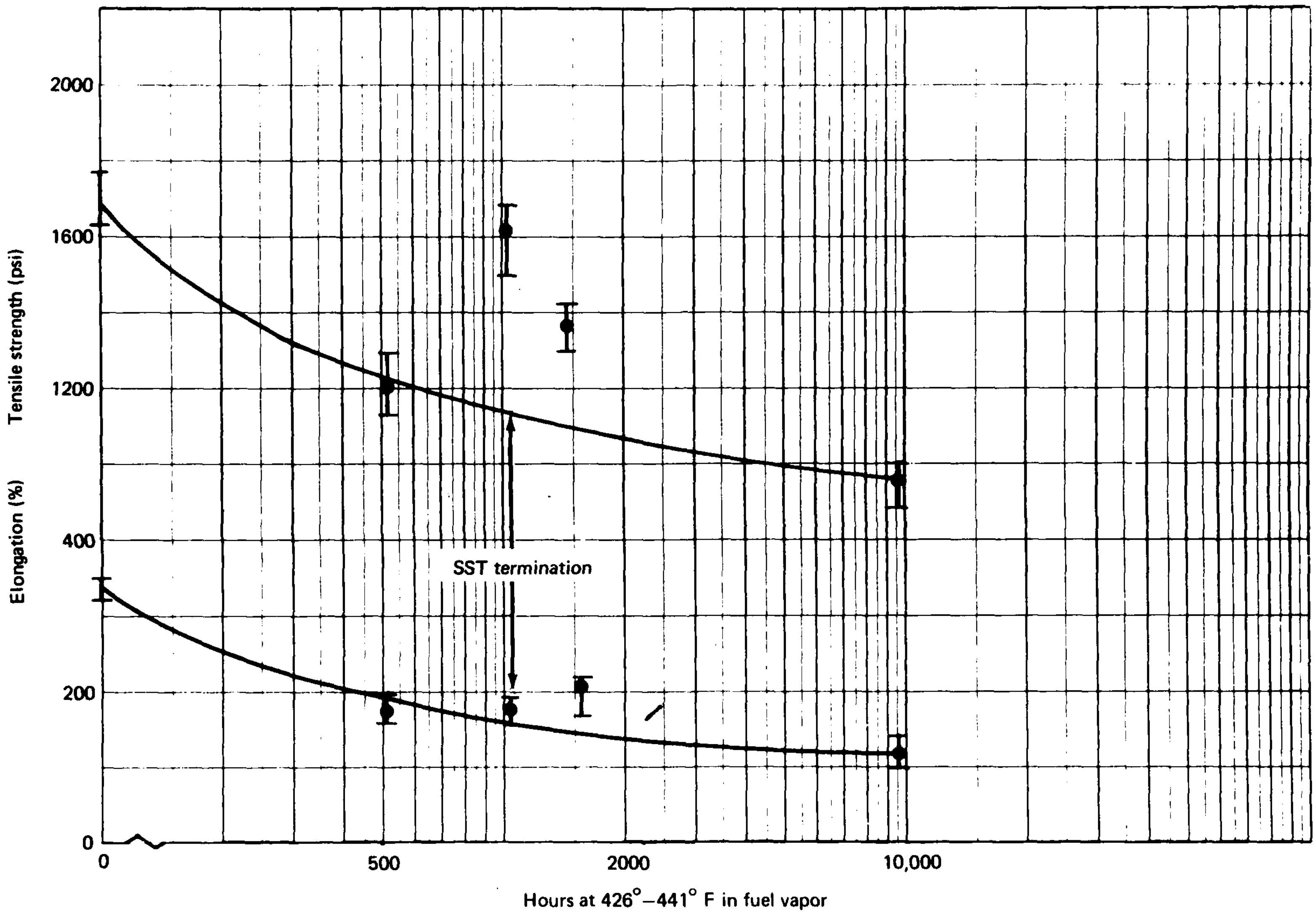


FIGURE 19.—ACCELERATED CYCLE EXPOSURE OF DC 77-028, LOT 206177, TESTED AT -50° F

	Hours of exposure at 426°–441° F in fuel vapor													
	0	149	287	433	1043	1344	1563	1994	2533	3437	4983	7675	9036	11,427
Shore A hardness	33	46	42	45	40	42	40	39	39	39	38	39	39	40
Peel (ppi/% coh)	—	—	—	—	—	—	—	—	—	—	95/60	—		
Weight change (%)		-1.1	-1.1	-1.5	-1.9	-2.1	-0.9	-1.8	-7.6	-3.1	-4.4	-6.2	-6.1	-7.5
Volume change (%)		-1.5	-1.8	1.6	-1.5	-2.5	-1.0	-2.1	-3.0	-3.7	-4.9	-7.2	-6.8	-8.4

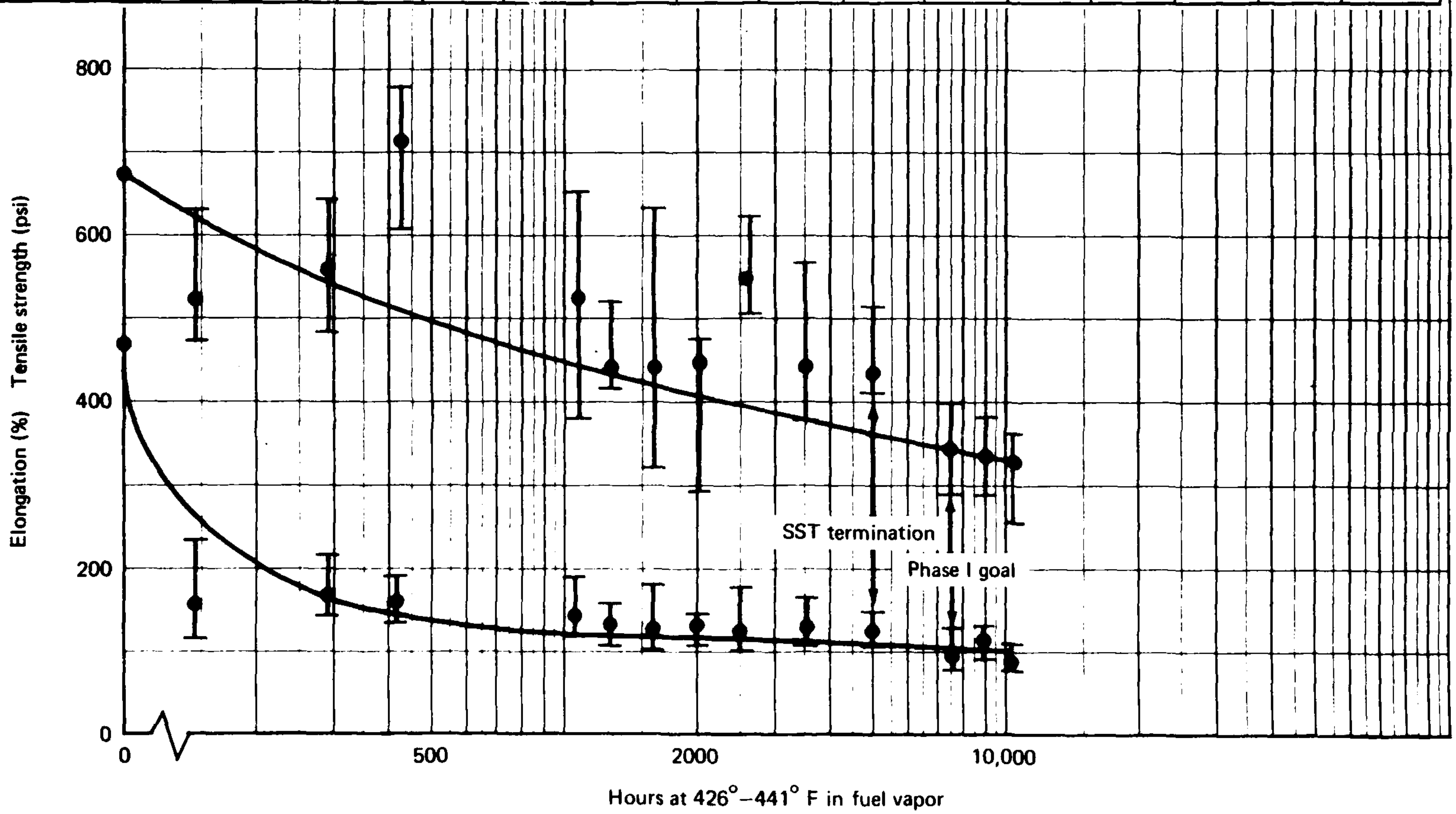


FIGURE 20.—ACCELERATED CYCLE EXPOSURE OF DC 77-028, LOT 1222, TESTED AT ROOM TEMPERATURE

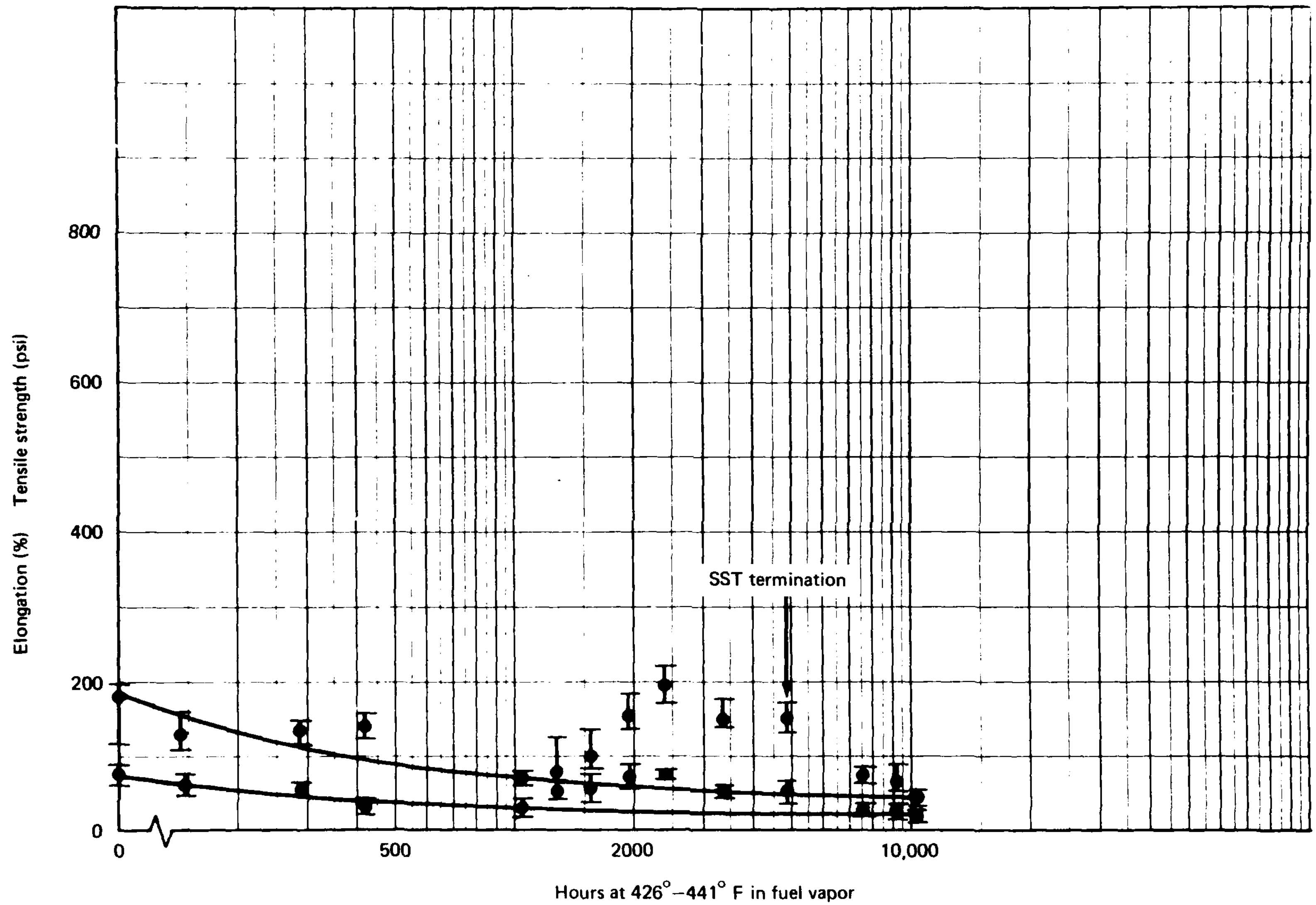


FIGURE 21.–ACCELERATED CYCLE EXPOSURE OF DC 77-028, LOT 1222, TESTED AT 450° F

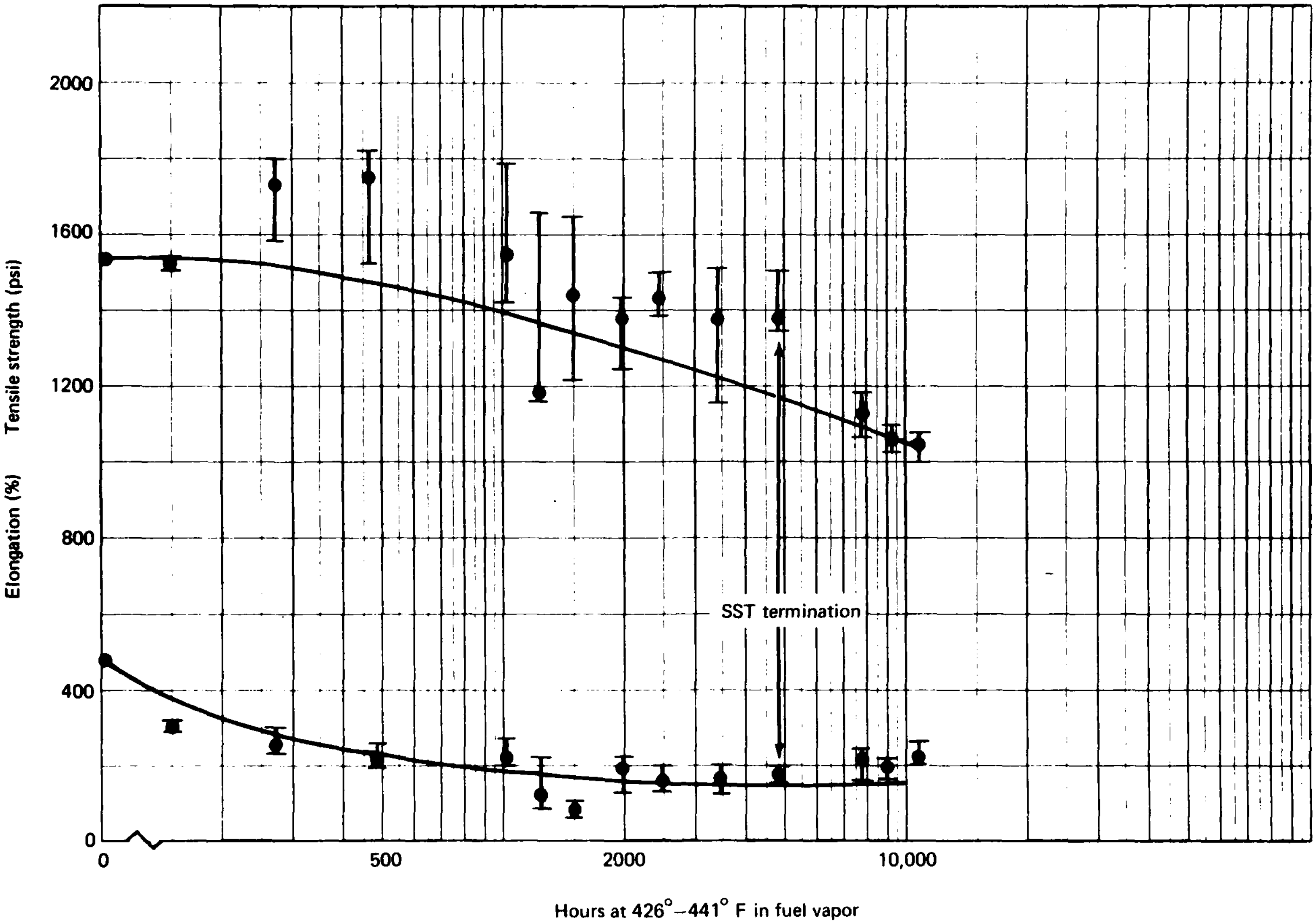


FIGURE 22.—ACCELERATED CYCLE EXPOSURE OF DC 77-028, LOT 1222, TESTED AT -50° F

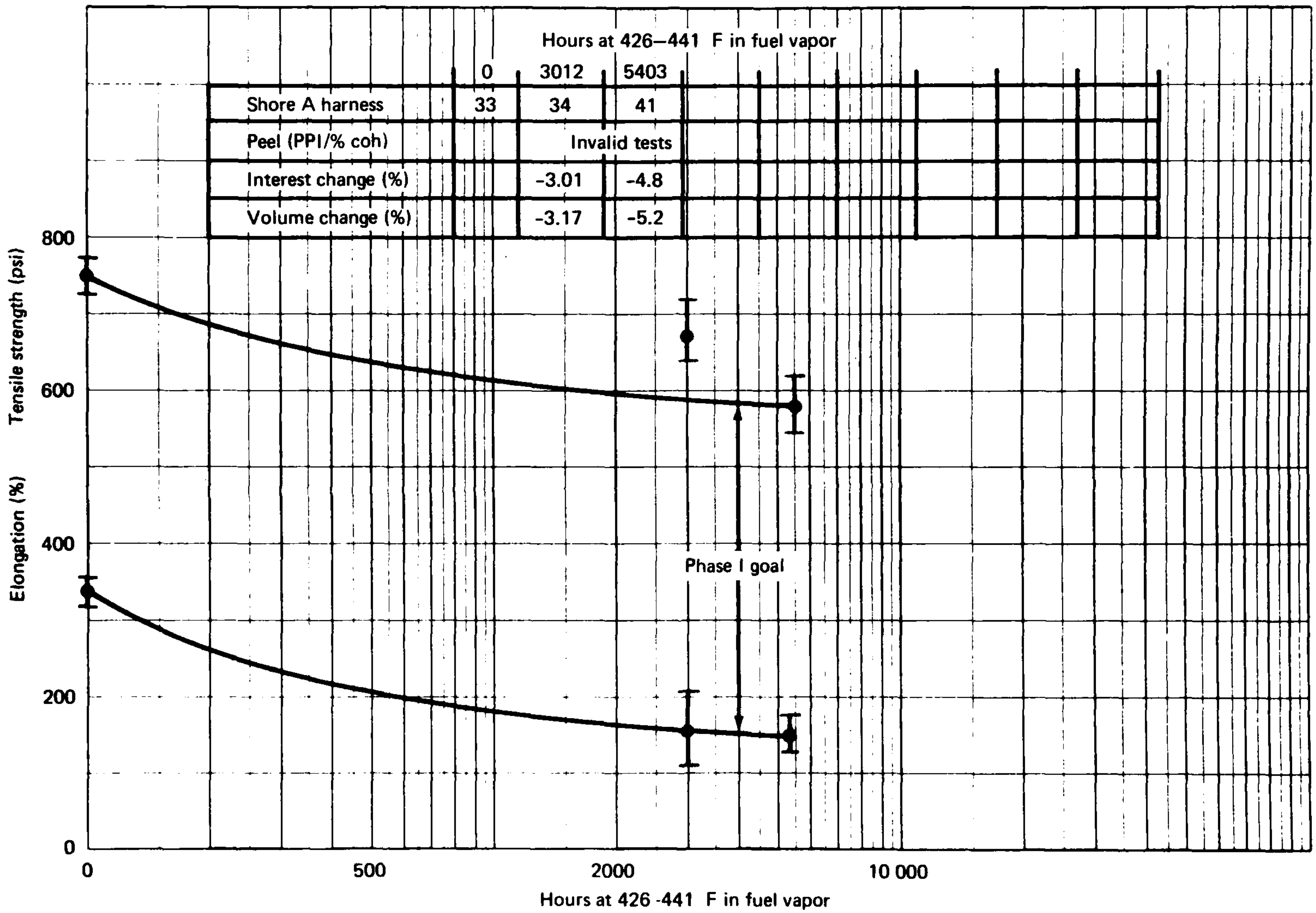


FIGURE 23. ACCELERATED CYCLE EXPOSURE OF DC 77-028, Lot 401117,
TESTED AT ROOM TEMPERATURE

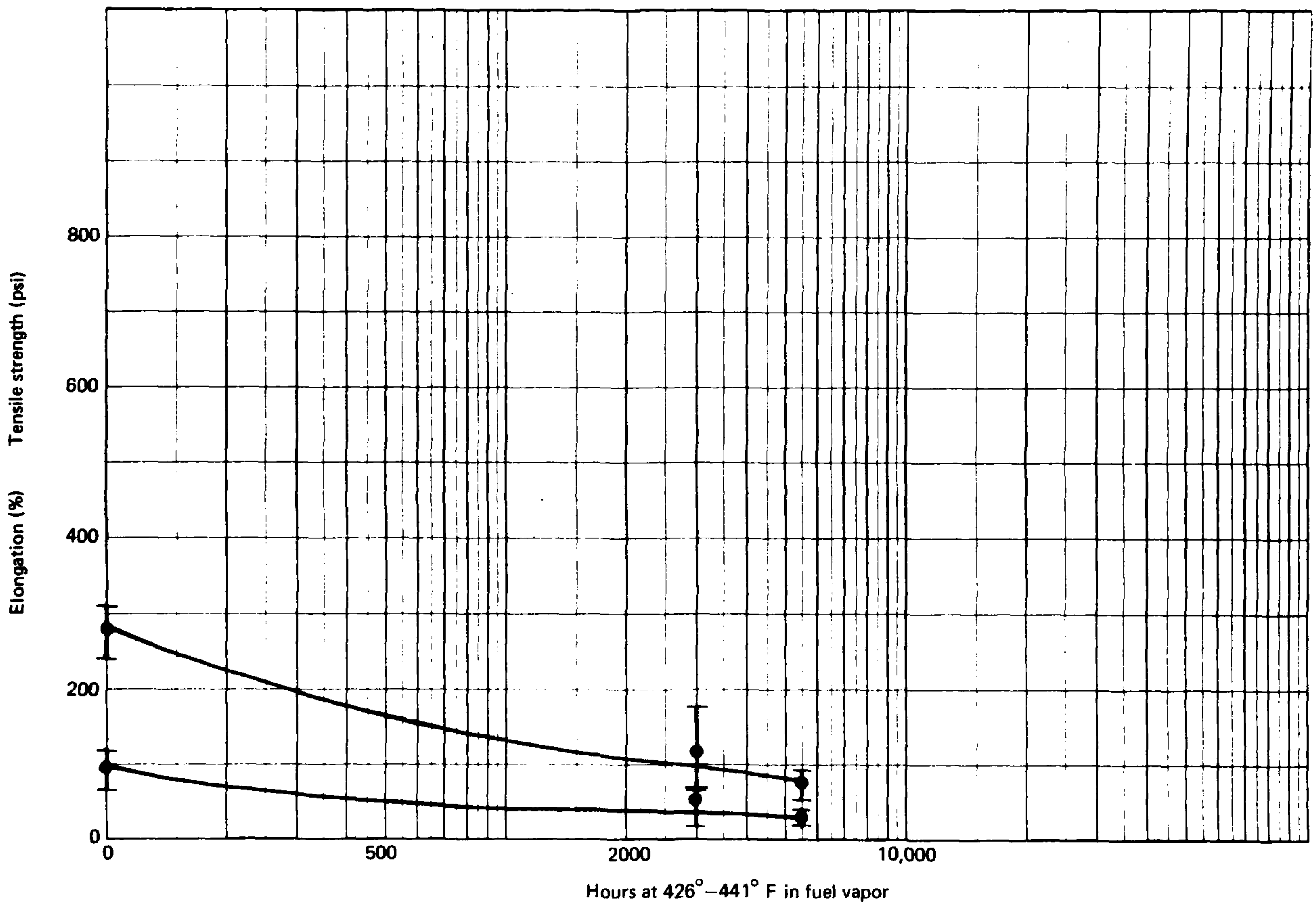


FIGURE 24.–ACCELERATED CYCLE EXPOSURE OF DC 77-028, LOT 401117, TESTED AT 450° F

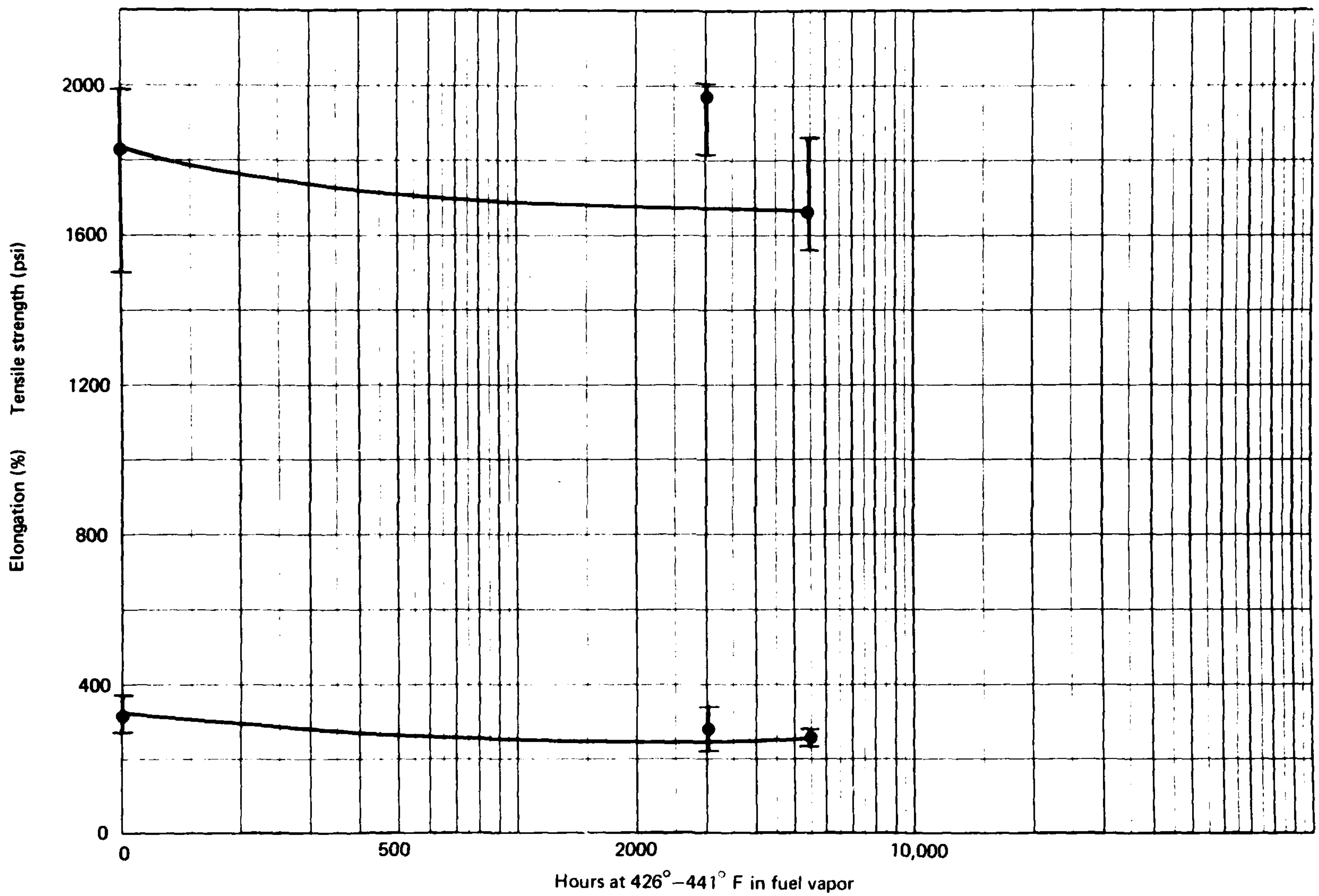
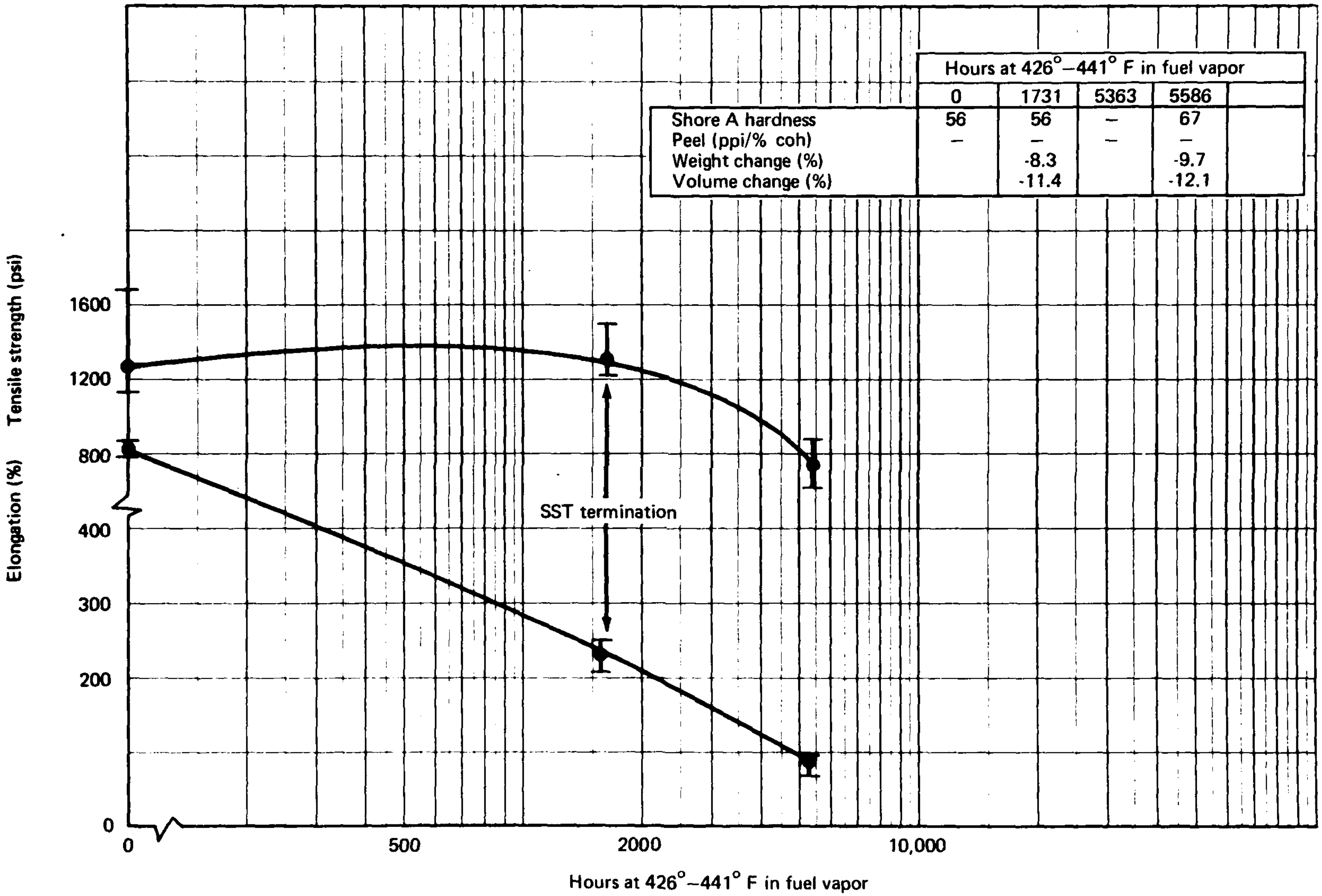


FIGURE 25.–ACCELERATED CYCLE EXPOSURE OF DC 77-028, LOT 401117, TESTED AT -50° F



	Hours at 426°–441° F in fuel vapor			
	0	1731	5363	5586
Shore A hardness	56	56	–	67
Peel (ppi/% coh)	–	–	–	–
Weight change (%)		-8.3		-9.7
Volume change (%)		-11.4		-12.1

FIGURE 26.–ACCELERATED CYCLE EXPOSURE OF AFML 397 TESTED AT ROOM TEMPERATURE

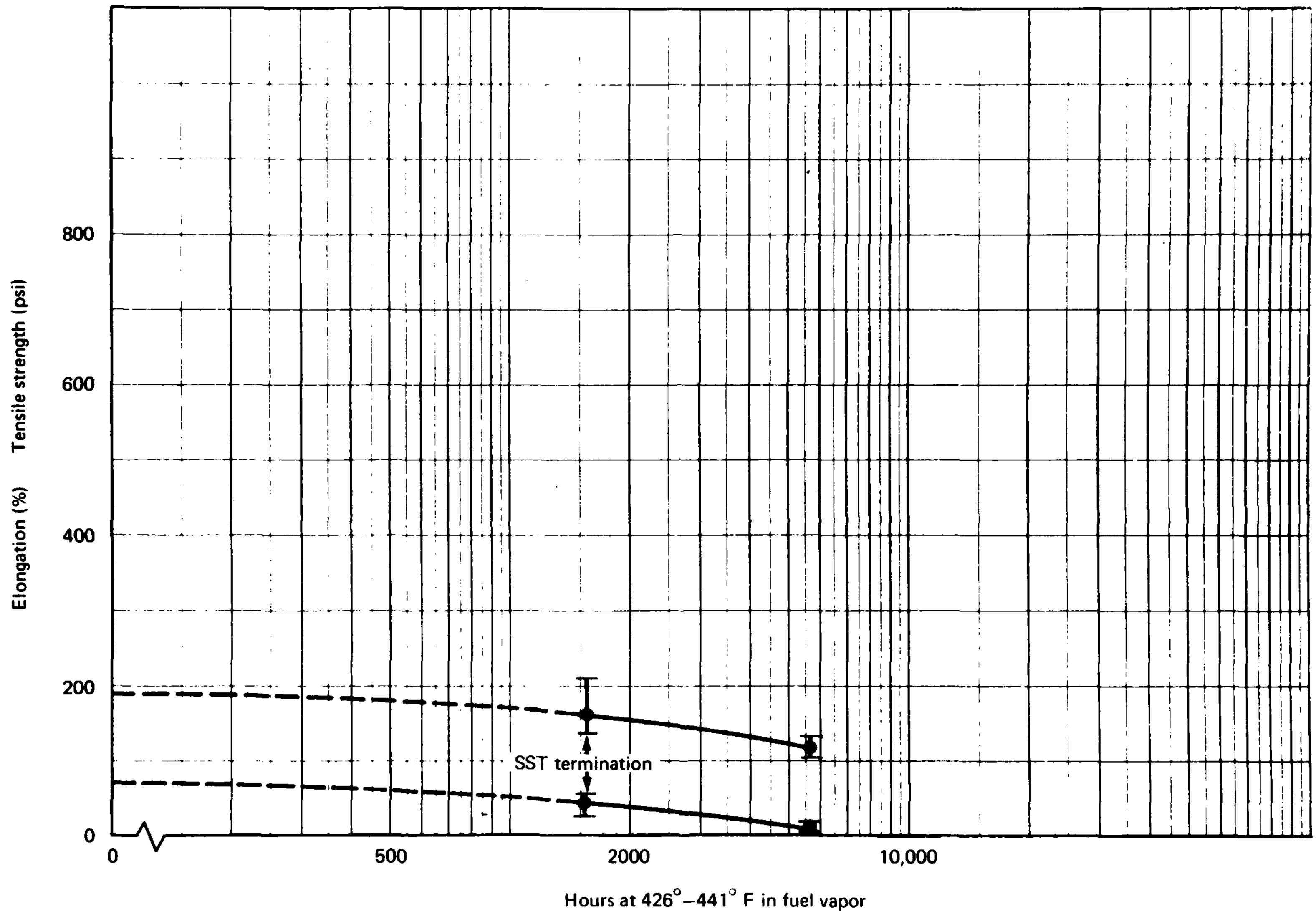


FIGURE 27.—ACCELERATED CYCLE EXPOSURE OF AFML 397 TESTED AT 450° F

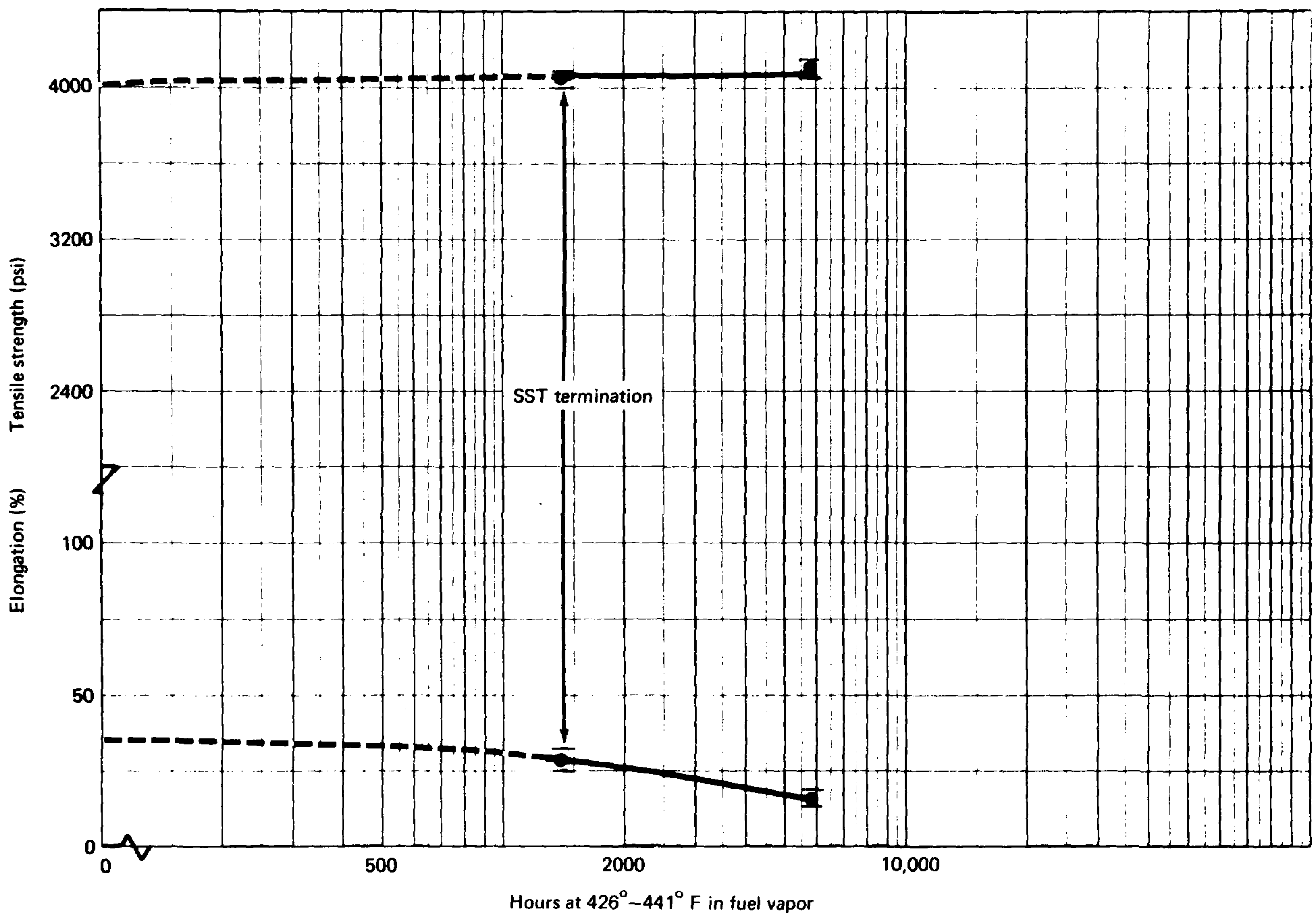
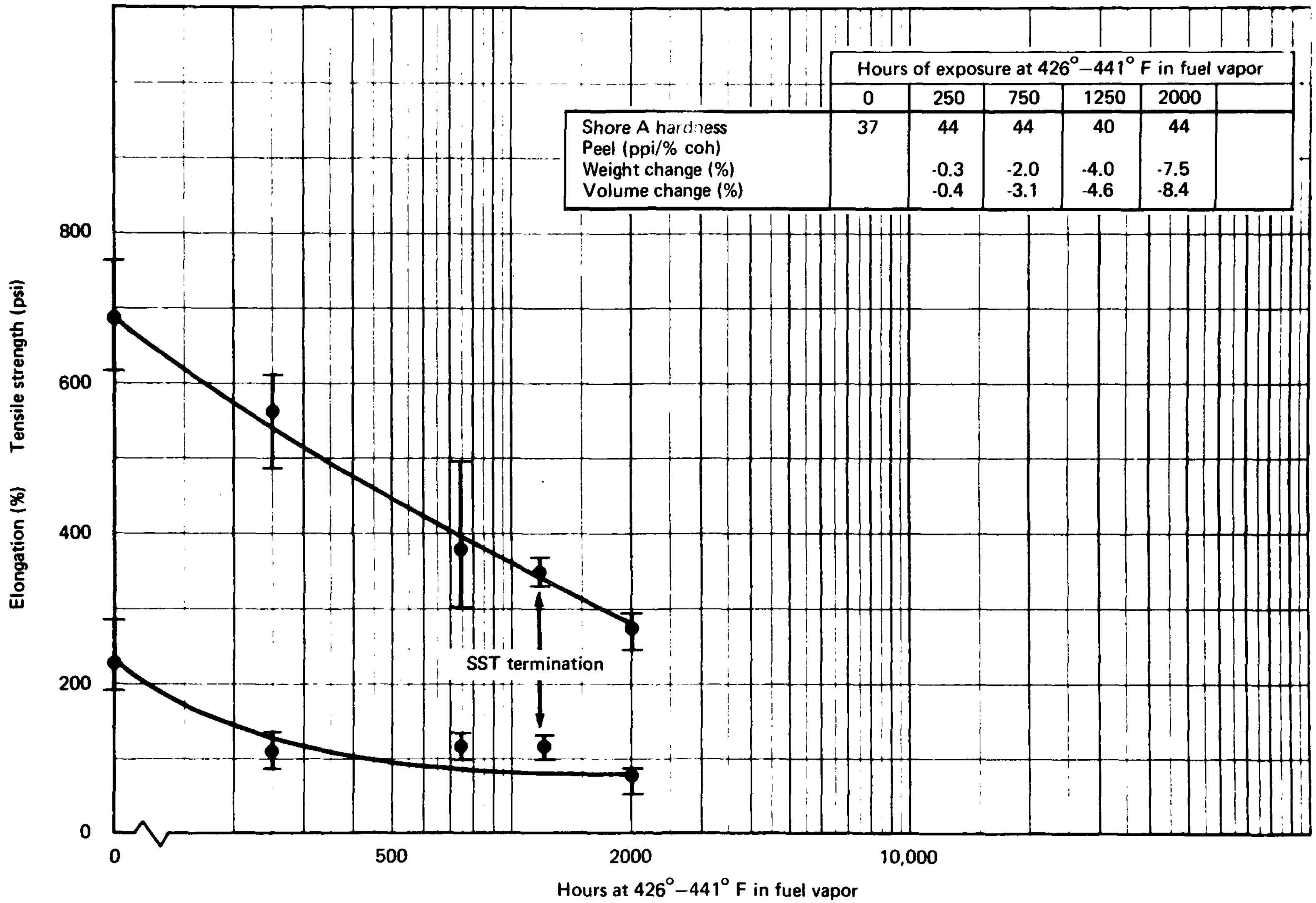


FIGURE 28.—ACCELERATED CYCLE EXPOSURE OF AFML 397 TESTED AT -50° F



	Hours of exposure at 426°–441° F in fuel vapor					
	0	250	750	1250	2000	
Shore A hardness	37	44	44	40	44	
Peel (ppi/% coh)						
Weight change (%)		-0.3	-2.0	-4.0	-7.5	
Volume change (%)		-0.4	-3.1	-4.6	-8.4	

FIGURE 29.—FLIGHT CYCLE EXPOSURE OF DC 77-028, LOT 206177, TESTED AT ROOM TEMPERATURE

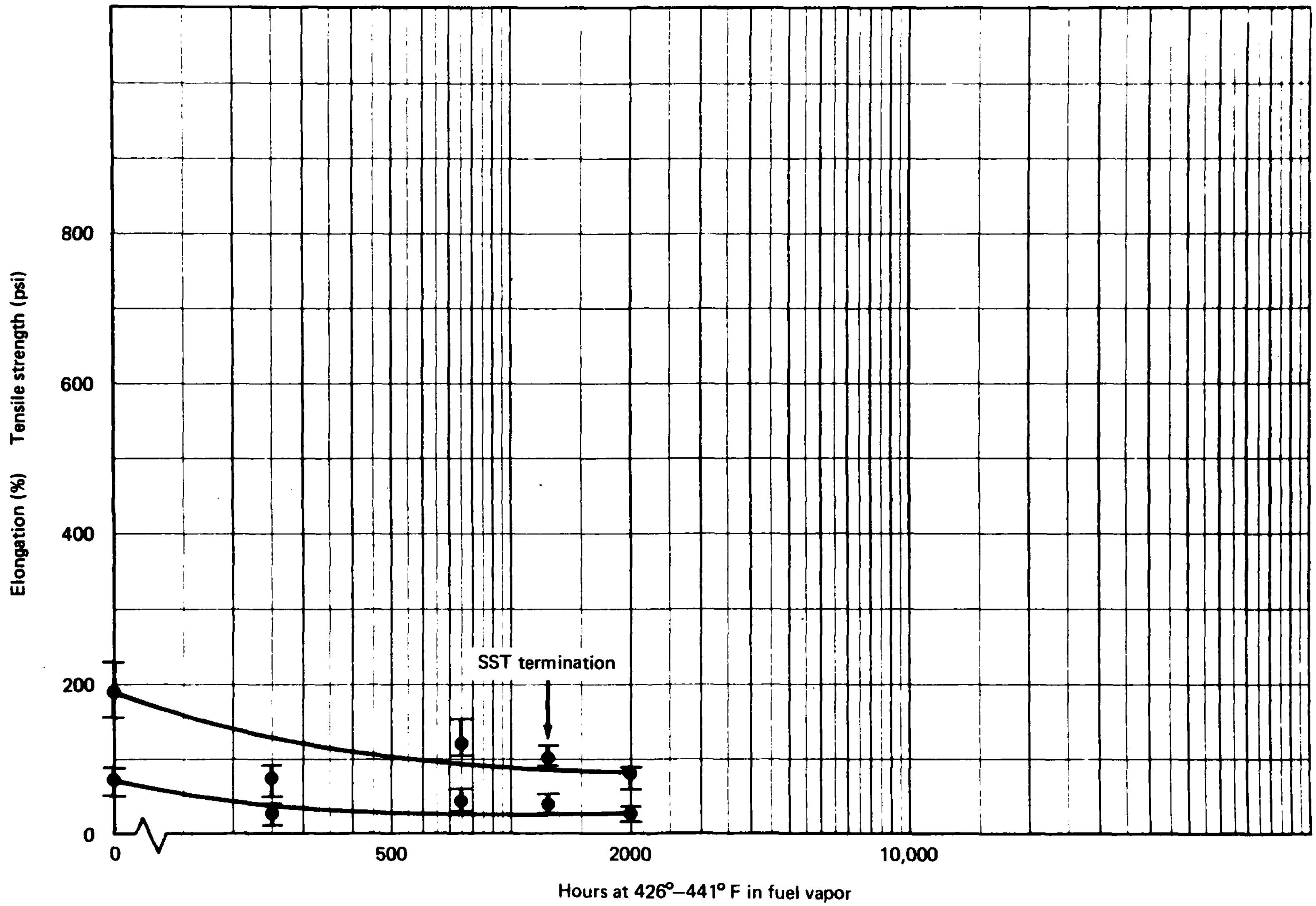


FIGURE 30.—FLIGHT CYCLE EXPOSURE OF DC 77-028, LOT 206177, TESTED AT 450° F

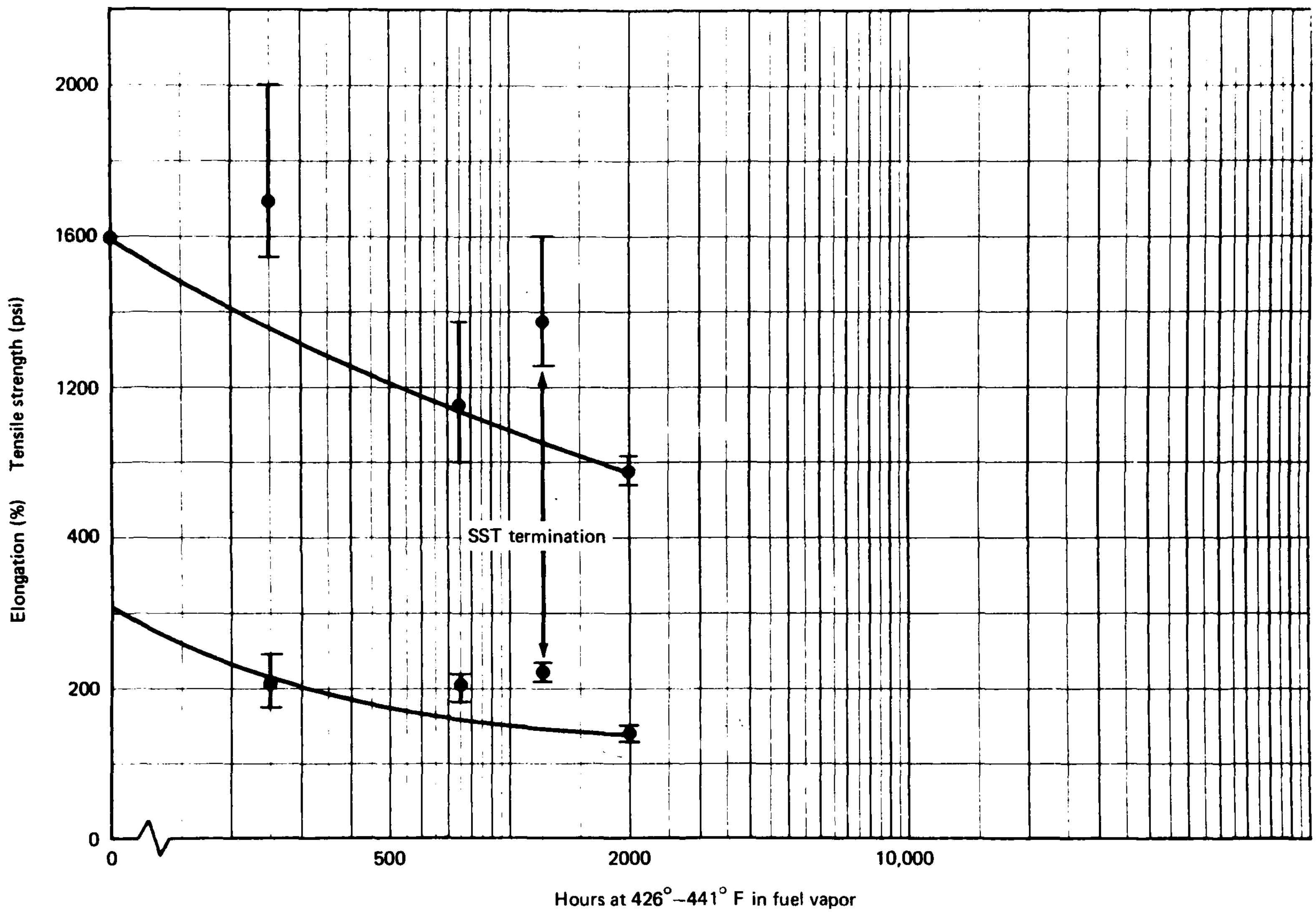


FIGURE 31.—FLIGHT CYCLE EXPOSURE OF DC 77-028, LOT 206177, TESTED AT -50° F

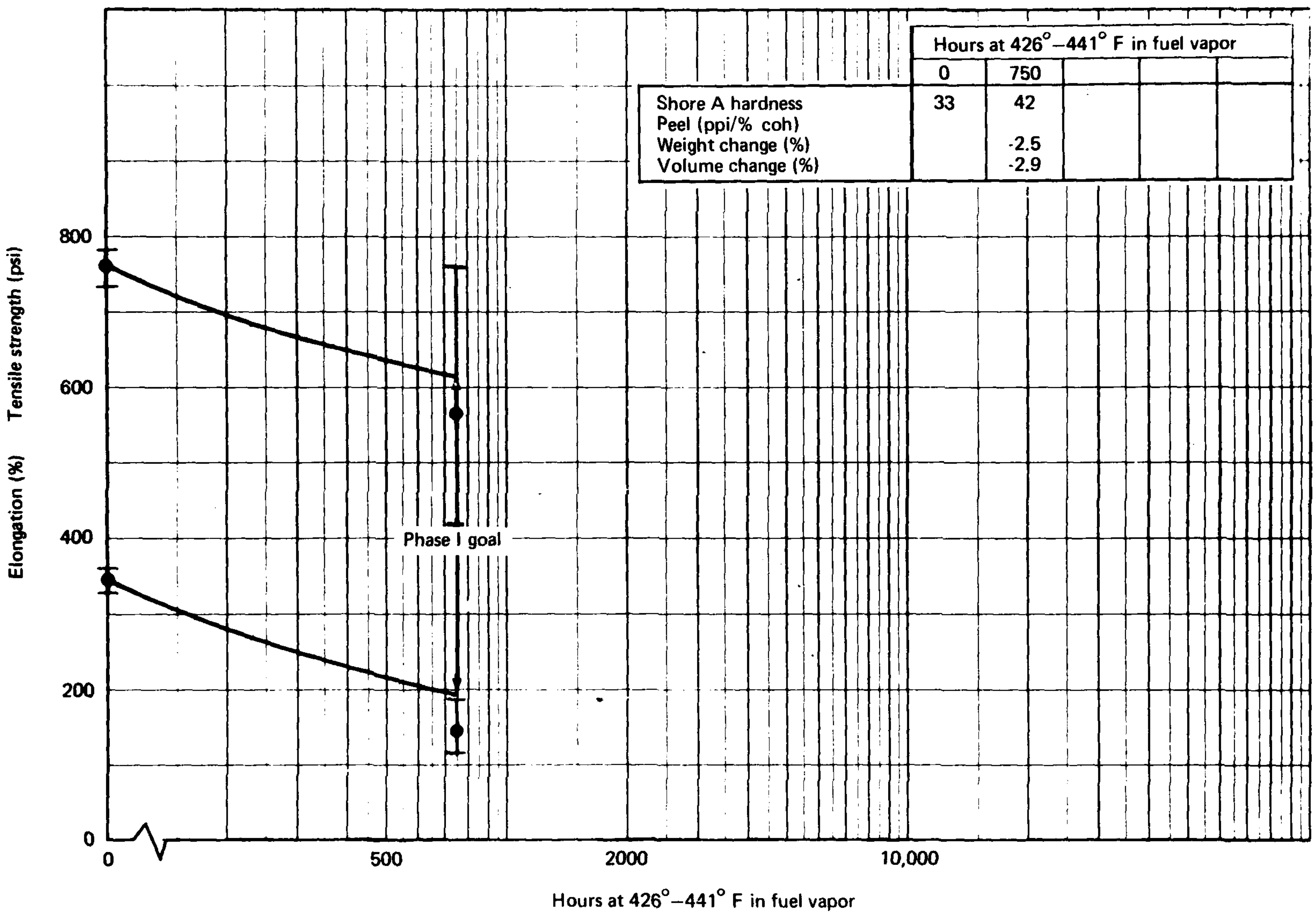


FIGURE 32.—FLIGHT CYCLE EXPOSURE OF DC 77-028, LOT 401117, TESTED AT ROOM TEMPERATURE

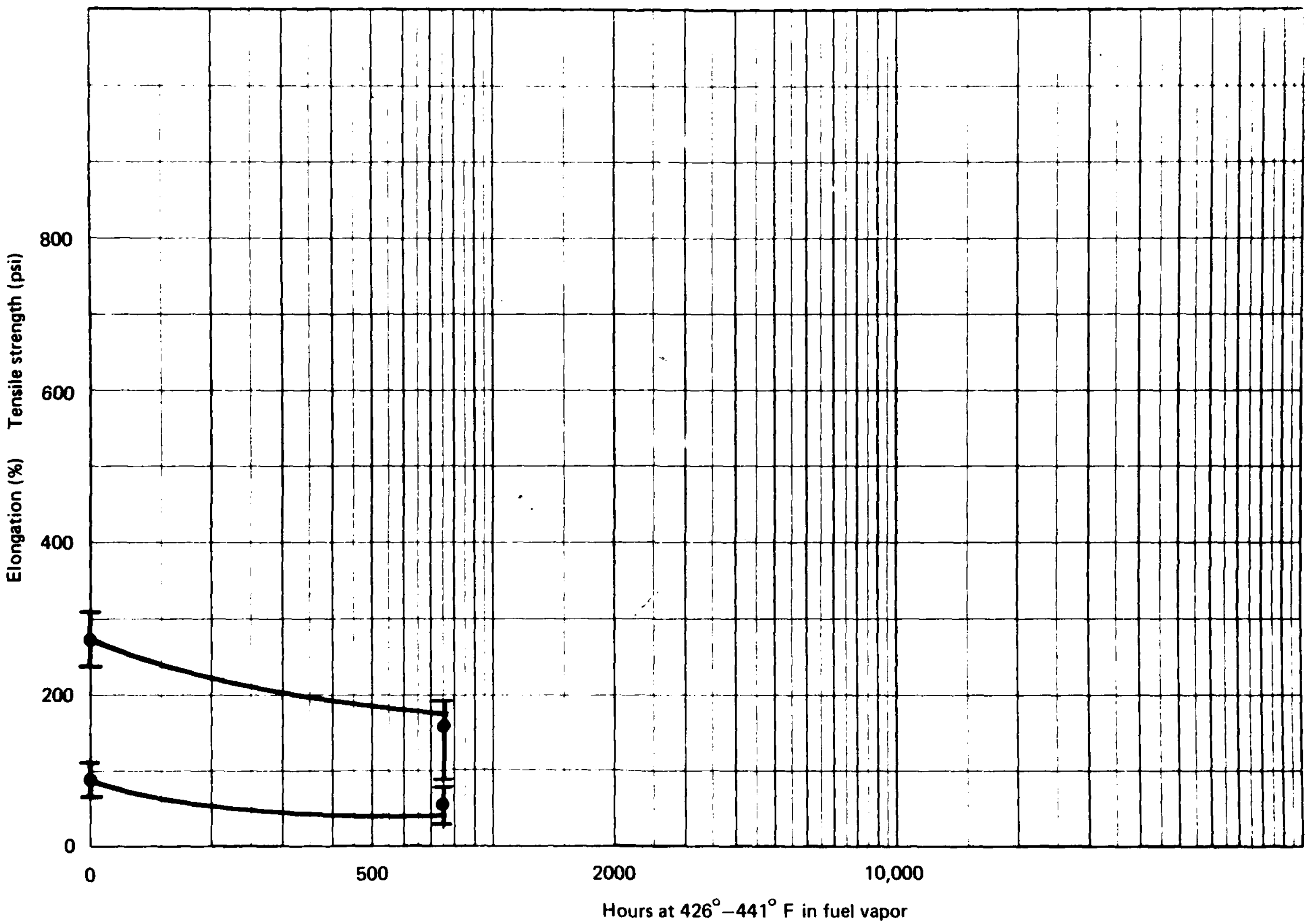


FIGURE 33.—FLIGHT CYCLE EXPOSURE OF DC 77-028, LOT 401117, TESTED AT 450° F

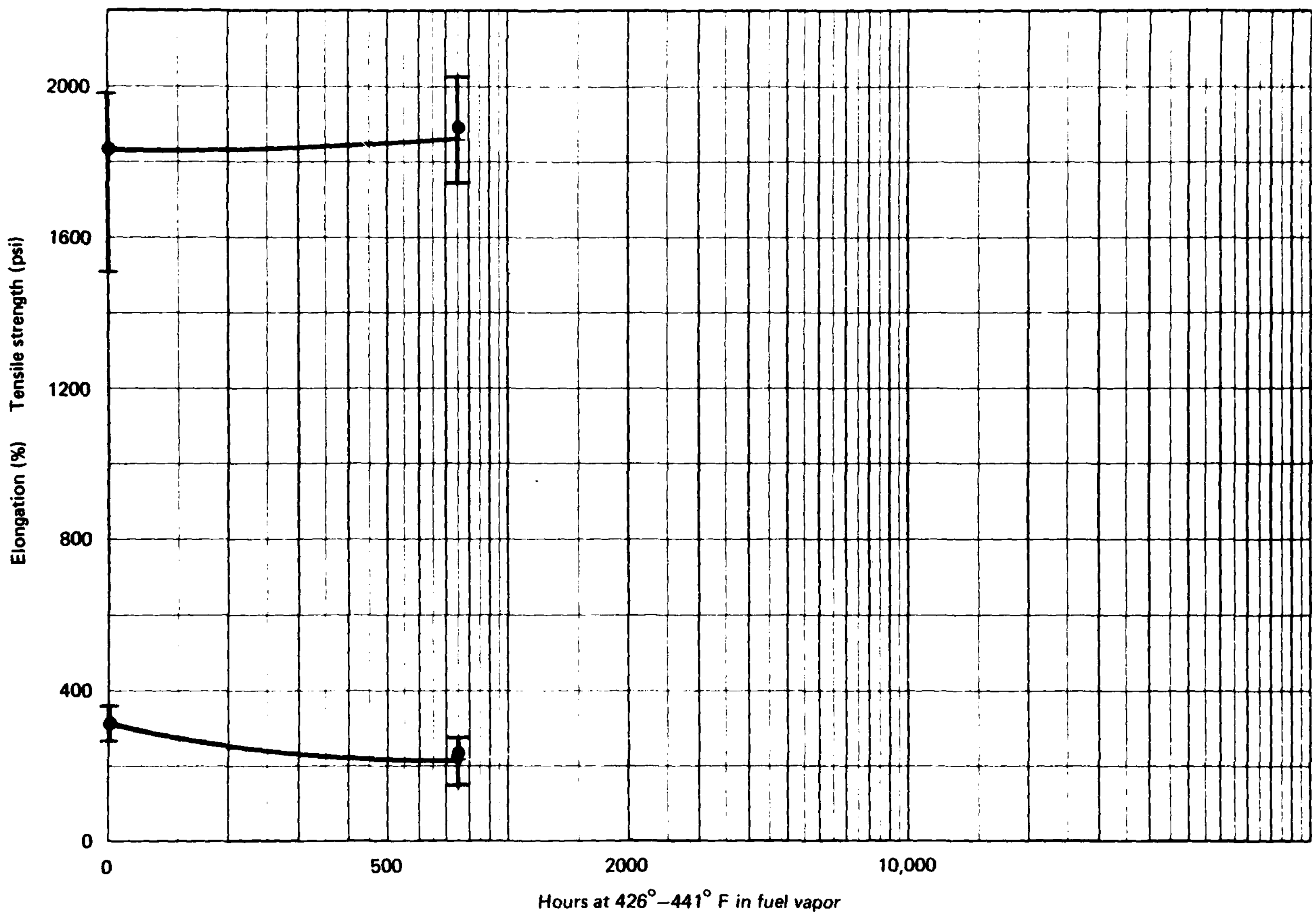
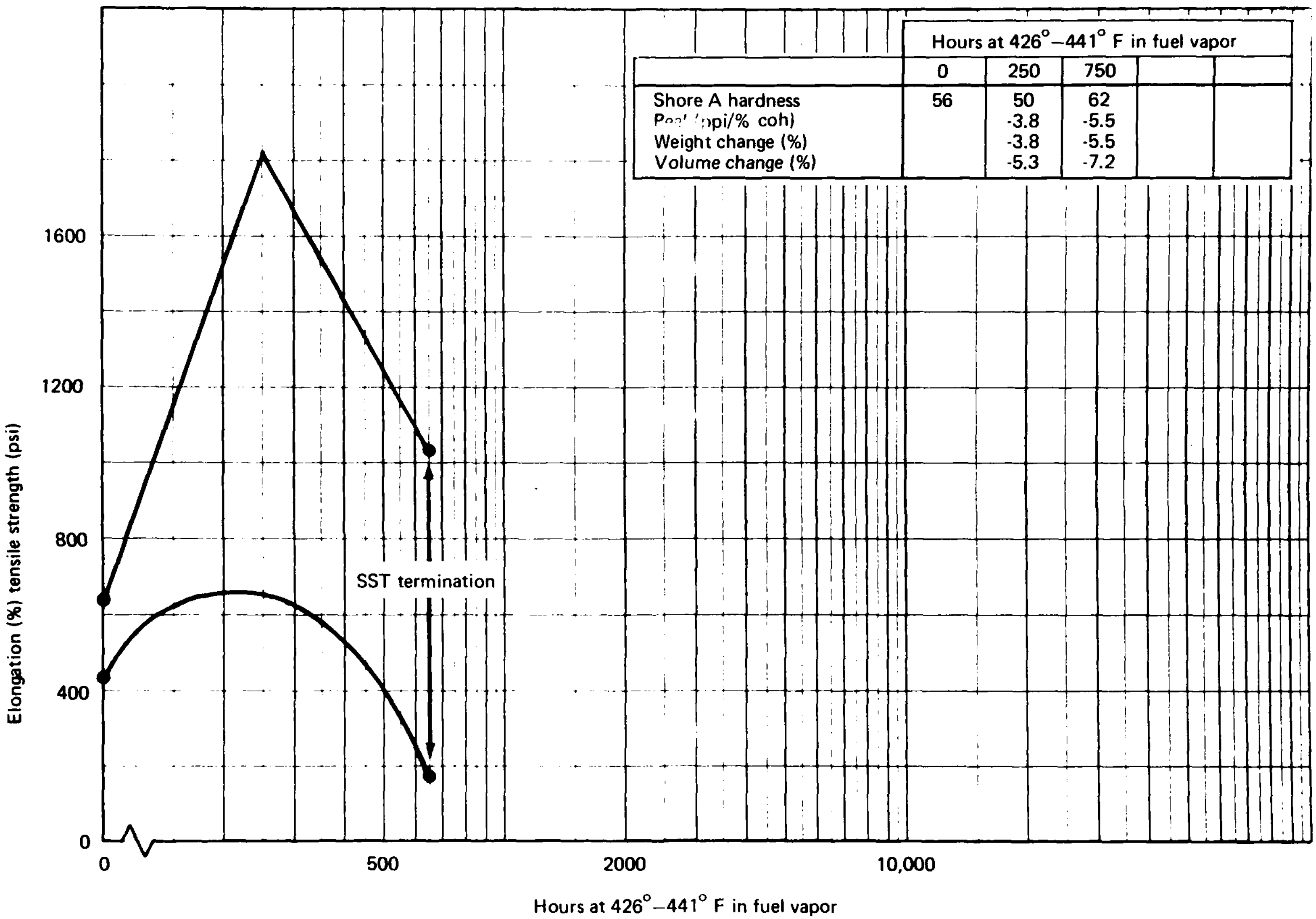


FIGURE 34.—FLIGHT CYCLE EXPOSURE OF DC 77-028. LOT 401117, TESTED AT -50° F



	Hours at 426°–441° F in fuel vapor				
	0	250	750		
Shore A hardness	56	50	62		
Peel (ppi/% coh)		-3.8	-5.5		
Weight change (%)		-3.8	-5.5		
Volume change (%)		-5.3	-7.2		

FIGURE 35.–FLIGHT CYCLE EXPOSURE OF AFML 397 TESTED AT ROOM TEMPERATURE

TABLE 1.—EFFECTS OF SPECIAL ENVIRONMENTS ON PROPERTIES OF DOW CORNING 94-516
(First set of specimens)

Property	Controls	Condition 1 (days)				Condition 2 (cycles)			Condition 3 (cycles)			Condition 4 (days)			
		4	13	24	45	1	3	6	1	3	6	4	16	24	45
Tensile strength (psi)	560	575	560	550	390	575	420	415	665	370	540	660	350	495	350
Elongation (%)	180	160	130	145	110	150	125	125	145	115	140	165	135	140	120
Adhesion	100% coh	—	—	—	—	100% coh	—	—	100% coh	—	—	—	100% coh	—	100% coh
Shore A hardness	38	42	45	40	43	46	38	47	46	43	47	36	35	36	38
Weight change (%)	—	-3.9	-2.6	-2.1	-6.0	-5.7	-8.2	*	-4.1	-7.1	-7.7	+3.1	0	-7.3	-9.2
Volume change (%)	—	-2.7	+1.0	+1.6	-4.0	-6.3	-8.3	*	-4.5	-6.5	-8.4	+3.4	+0.1	-8.1	-9.7

Description of exposure conditions

Condition 1
- 450°F (chamber wall)
- *Liquid fuel*
- 55,000- to 62,000-ft pressure
- Recycle fuel
- Air bleed

Condition 2
- 160°F (fuel)
- 18,000-ft pressure
- Air bleed

} 3 days

- 450°F (fuel vapor)
- 55,000- to 62,000-ft pressure
- Recycle fuel
- Air bleed

} 4 days

Condition 3
- Same as condition 2 *except 3% salt water* in fuel
- Water/fuel ratio = 1/10

Condition 4
- Same as second phase of condition 2

*Not measured; specimens stuck together

Notes:
1. All fuel saturated with water at room temperature
2. In condition 2, fuel vapor was at 515°F during second cycle for a time not exceeding 16 hr and vacuum was lost
3. In conditions 3 and 4, fuel vapor was at 480° to 490°F during second cycle for a time not exceeding 16 hr and vacuum was lost

TABLE 2.—EFFECTS OF SPECIAL ENVIRONMENTS ON PROPERTIES OF DOW CORNING 94-516
(Second set of specimens)

Property	Controls	Condition 2 (cycles)			Condition 3 (cycles)			Condition 4 (days)	
		3	6	10	3	6	10	26	42
Tensile strength (psi)	560	595	750	430	655	805	660	570	595
Elongation (%)	180	135	145	160	140	140	165	140	145
Shore A hardness	38	49	45	36	50	46	45	44	43
Weight change (%)	–	-2.3	-10.5	-6.2	-6.9	-9.1	-10.6	-7.5	-6.7
Volume change (%)	–	-0.7	-9.3	-4.7	-7.4	-9.5	-11.0	-7.8	-6.8

Notes:

1. Description of exposure conditions same as for first set of specimens
2. All fuel saturated with water at room temperature

3.3 ADHESION TO MATERIALS OTHER THAN TITANIUM

The surface treatment used and test results are shown in table 3. Adhesion to titanium alloys was being maintained but is questionable with stainless steels, aluminum, and copper. The best adhesion was to nickel clad steel and clad aluminum.

3.4 COMPATIBILITY WITH AIRCRAFT AND MANUFACTURING FLUIDS

(A) Fuel (ASTM D-1655 Jet A), hydraulic fluid (Humble WSX7597M), engine lubricant (Texaco SATO 7730), heat transfer fluid (Dow Corning 331), shock strut fluid (Mobil RM 184A), and deicing fluid (MIL-A-8243 type C), a mixture of 90% fuel and 10% hydraulic fluid, and a mixture of 10% shock strut fluid and 90% fuel.

Results are shown in table 4. Except for the deicing fluid, the effect was less than that on the control specimens.

TABLE 3.—ADHESION OF DOW CORNING 77-028 TO VARIOUS SUBSTRATES

Substrate	Surface Treatment[a]	Hours of 450° F Air Aging	
		Satisfactory Adhesion[c]	Adhesive Failure[c]
Titanium alloys			
6-4	Machined	1060	
	Machined and cleaned[b]	1060	
8-1-1	None	1108	
	Machined	1200	
	Machined and cleaned[b]	1200	
3-2.5	None	1135	
Beta III	None	1068	
	Not primed	1068	
CP	None	1100	
Stainless steel alloys			
321	Passivated[b]	67	138
	Sandblasted	482	644
Custom 455	Passivated[b]	138	200
	Sandblasted		860
PH 17-7	None	1200	
	Sandblasted	1200	
PH 17-4	Passivated[b]	0	67
	Sandblasted	1016	1134
Inconel 625	Passivated[b]	67	138
	Sandblasted	834	998
MP35N	None	834	998
	Sandblasted	834	998
		Cohesive Failure	Adhesive Failure
Aluminum alloys			
2024	None	452	644
Clad	None	1644	
	No primer	1644	
2024	Alodine	654	792
7075	Anodize	654	792
Nickel-plated steel	None	1054	
Copper	None	0	192
Polyimide adhesive	None	Failed in adhesive after 456 hr	

[a] All specimens were cleaned and primed per section 2.2.1. Where noted, primer was deleted on some specimens.

[b] Nitric-hydrofluoric acid etch.

[c] Adhesion is satisfactory when adhesion to substrate is greater than cohesive strength of sealant. The hours of 450°F aging are the last test point at which adhesion was satisfactory or the first test point at which adhesion failure was noted.

Note: All specimens used sealant lot 104158 and primer lot 232-87

TABLE 4.—EFFECTS OF EXPOSURE TO VARIOUS FLUIDS ON TENSILE PROPERTIES OF DOW CORNING 77-028, LOT 104158

Total hours in fluid at 160°F	Total hours at 450°F and 29 in. Hg	Fluid	Tensile strength (psi)	Elongation (%)
10	19	Air (control)	185	191
		Fuel (control)	237	199
		Sato 7730 (Texaco) turbine oil	214	164
		MIL-A-8243, Type C de-icing fluid	153	129
		DC 331 heat transfer fluid	193	208
		WS 7597 (Humble) hydraulic fluid	198	209
		10% RM 184A (Mobil) shock strut fluid in fuel	235	185
		10% WS 7597 hydraulic fluid in fuel	453	171

Notes:
1. Specimens were exposed to cycles consisting approximately of: 1 hr in test fluid at 160°F and 2 hr at 450°F and 29 in. of mercury vacuum.
2. Lot 104158 had the following initial values:
   Tensile strength: 669 psi
   Elongation: 312%

(B) Anti-icing fluid (Phillips PFA 55MB)

Results are shown in table 5. DC 77-066 is a low-expansion version of DC 77-028 planned for use as the the injection sealant. There were no significant effects on the DC 77-028 filleting sealant under any test condition. Specimens of the DC 77-066 injection sealant immersed in the fuel layer of the test fluid were softened and had a substantially lower modulus after the 10-day, 160°F immersion period. The control fluid had no such effect. When immersion in the fuel layer of the test fluid was followed by a 7-day, 450°F exposure, the softening trend was apparently reversed.

Exposure to the water layer of the fluids had the most drastic effects on DC 77-066. The 10-day, 160°F exposure to the control fluid produced a high-volume swell, a lower shore A hardness, and reduced tensile strength and elongation. With the presence of the anti-icing additive, these effects were greatly magnified. When water immersion was followed by a 450°F exposure, there was still a large reduction in tensile strength and elongation, both with and without the additive.

Titanium U-bend stress corrosion specimens were subjected to the same exposure conditions simultaneously with the sealants. No corrosion was observed.

TABLE 5.–COMPATIBILITY OF FUEL SEALANT AND TITANIUM WITH FUEL AND WATER MIXTURES CONTAINING PFA 55MB FUEL ADDITIVE

	Initial	3 days at 160°F+ 7 days at 450°F	3 days in fuel at 160°F + 7 days at 450°F	3 days in fuel (PFA 55MB added) at 160°F + 7 days at 450°F	3 days in water at 160°F + 7 days at 450°F	3 days in water/PFA 55MB at 160°F + 7 days at 450°F	10 days in fuel at 160°F	10 days in fuel (PFA 55MB added) at 160°F	10 days in water at 160°F	10 days in water/PFA 55MB at 160°F
Dow Corning 77-028										
Tensile strength (psi)	735	585	480	595	500	550	515	580	580	555
Elongation (%)	325	150	135	160	135	150	250	290	320	300
Shore A hardness	26-28		38	38	43	38	24	24	25	26
Weight change (%)			-1.9	-1.9	-5.2	-2.3	+3.9	+4.1	+5.2	+6.0
Volume change (%)			-2.5	-2.7	-6.3	-3.0	+7.0	+7.2	+8.7	+9.5
Adhesion	Cohesive failure of the sealant in all cases									
Dow Corning 77-066										
Tensile strength (psi)	245	415	425	405	265	150	280	215	145	40
Elongation (%)	65	55	50	50	30	30	45	100	50	95
Shore A hardness	64-67		73	73	73	64	64	56	52	16
Weight change (%)			-1.2	-1.0	-1.2	+1.1	+1.3	+1.4	+6.7	+12.0
Volume change (%)			-2.4	-2.1	-2.2	+1.0	+3.4	+3.5	+13.9	+24.1
Adhesion	Cohesive failure of the sealant in all cases									
Titanium compatibility	No corrosion in any of the exposure conditions									

(C) Leak detection materials

Table 6 shows the effect. If not removed prior to 450° F exposure, any paint or soap apparently causes sealant degradation.

(D) Cutting fluids (TB-1 and water)

Results are shown in table 7. None of the fluids affected sealant adhesion.

3.5 WATER

Test results of fillet peel specimens are shown in table 8.

3.6 TITANIUM COMPATIBILITY

Neither the fluorosilicone nor the Viton 487-based sealants caused stress corrosion of titanium.

TABLE 6.—COMPATIBILITY OF LEAK INDICATORS WITH 77-028 FUEL SEALANT

Exposure	Tensile strength (psi)	Elongation (%)	Hardness (Shore A)
Controls—168 hr at 450° F	610	150	40-41
24 hr in indicator followed by 168 hr at 450° F			
Snoop	315	105	38-42
Turco indicator paint	210	75	39-42
Tereco car shampoo	250	95	40-42
Fuller O'Brien indicator paint	205	70	40-41
NH_3 indicator gas (12% NH_3 air mixture)	550	130	43
24 hr in indicator, spray washed 30 sec followed by 168 hr at 450° F			
Snoop	505	155	39-43
Turco	520	160	39-43
Tereco	605	165	39-43
Fuller O'Brien	580	165	39-43
Controls—24 hr in fuel followed by 168 hr at 450° F	700	155	42
24 hr in dyed fuel (0.1 g/200 ml fuel) followed by 168 hr at 450° F	652	135	—

TABLE 7.—ADHESION OF SEALANT TO SURFACES CLEANED WITH VARIOUS FLUIDS

Specimen	Surface cleaned with	Recleaned prior to priming with	Recleaning of primer	Adhesion	
				Initial	After five accelerated cycles (1130 hr at 440°F and 100 hr fuel at 140°F)
1	Cleaner (sec. 2.2.1)	None	None	Cohesive	Cohesive
2	H_2O	None	None	Cohesive	Cohesive
3	H_2O	Cleaner (sec. 2.2.1)	None	Cohesive	Cohesive
4	TB-1	None	None	Cohesive	Cohesive
5	TB-1	Cleaner (sec. 2.2.1)	None	Cohesive	Cohesive
6	Cleaner (sec. 2.2.1)	None	Hexane	Cohesive	50% cohesive (edges)
7	Cleaner (sec. 2.2.1)	Primer dried 30 min at 250°F	Cleaner (sec. 2.2.1)	Cohesive	Cohesive
8	Cleaner (sec. 2.2.1)	None	None	Adhesive	–
9	Cleaner (sec. 2.2.1)	None	H_2O	Cohesive	Cohesive
10	Repeat of 6 using more vigorous scrubbing with hexane			Adhesive	
11	Cleaner (sec. 2.2.1)	None	Isopropyl alcohol	Adhesive	

TABLE 8.—EFFECT OF WATER EXPOSURE ON FUEL TANK SEALANTS

Water exposure	Type of failure		
	DC 77-028	DC 77-053	DC 77-066
1. Two weeks at room temperature	All cohesive	All adhesive*	All cohesive
2. Same as 1 plus 2 hr boil at 1 psia	All cohesive	All cohesive	All cohesive
3. Same as 2 plus accelerated cycle	All cohesive	All cohesive	All cohesive

*Specimens cured for 6 hr at 160°F all exhibited cohesive failure

3.7 REVERSION RESISTANCE

Reversion resistance tests and resistance to extruding and tearing go together since reversion is more likely to happen when the sealant is confined. Various tests were performed as follows:

(A) Dow Corning 77-066 was placed in tubes of various diameters and lengths with open ends. The sealant reverted after 3-day exposure at 450°F when a minimum length was exceeded. For various diameters, the lengths at which reversion did and did not occur are listed in table 9.

TABLE 9.—EFFECT OF CONFINEMENT DIMENSIONS ON REVERSION

Inside diameter (in.)	Reversion (in.)	No reversion (in.)
1/8	15	10
1/4	15	10
7/16	19	15

(B) Dow Corning 77-053, a version of DC 77-028 compounded for faying surface sealing, was placed in 3- and 6-in. tubes with diameters of 0.25, 0.38 and 0.5 in. After 240 hr, there was no reversion.

(C) Dow Corning 77-028 was placed in a faying surface of 3- by 6-in. dimensions. After 2 weeks at 450°F, the sealant was soft but did not appear reverted.

(D) Three-inch-long injections of various cross-sectional configurations were prepared using Dow Corning 77-028, 77-053, and 77-066. Thermal extrusion at 450° F was measured. Results are shown in table 10.

TABLE 10.—EFFECT OF CONFINEMENT DIMENSIONS ON EXTRUSION

Injection hole		Total thermal extrusion[a] (in.)		
Size (in.)	Shape	77-028[b]	77-053[c]	77-066[d]
0.50 by 0.50	Square	0.56	0.20	0.16
0.25 by 0.25	Square	0.63	0.15	0.14
0.15 by 0.15	Square	0.44	0.10	0.10
0.10 by 0.10	Square	0.25	0.08	0.13

[a] Measurements were made at both ends of injection and added together to obtain total extrusion.

[b] Sealant was torn and dislodged from sides of injections.

[c] Sealant was still bonded to sides of injection. The 0.5- by 0.5-in. injection had a surface crack.

[d] Sealant was still bonded to sides of injection. The 0.10-by 0.10-in. injection extruded 0.10 in. on one side and 0.03 in. on the other.

(E) Fillet seals were applied over 3-in.-long injection seals of various cross-sectional configurations. DC 77-028 was used for both the fillets and the injections. After 24 hr at 450° F the fillets were examined for damage. Results are shown in table 11. Figure 36 illustrates the effect of thermal expansion when injection seals are used. Not only does the sealant extrude and tear itself, but the fillet of sealant which normally covers the injection seal may be dislodged. To ascertain the extent of this problem, fillet seals of Dow Corning 77-028 were applied over 3-in.-long injections of various cross-sectional configurations. Injections were Dow Corning 77-066. After 24 hr at 450° F, the fillets were examined for damage. Results are shown in table 12.

(F) A number of methods were tried to limit the extrusion. One, shown in figure 37, was to fill tubes of 0.625-in. inside diameters with DC 77-028. Metal plugs of various diameters were pushed into the sealant, then the sealant was cured. The tubes were subjected to 450° F exposure for 48 hr, then checked for thermal extrusion. Results are shown in table 13. No damage occurred to the sealants after the first exposure to 450° F. After 4 weeks at 450° F, cracking occured on all sizes.

(G) Another method was to add a foaming agent to DC 77-028. In one test Dow Corning 77-053, 77-066, and 77-028 with 4% Nitrosan were placed in 6-in. tubes with diameters of 0.25, 0.38, and 0.5 in. After 768 hr of 450° F exposure, 77-028 had reverted. The other two sealants did not revert, and no damage from thermal extrusion was noted.

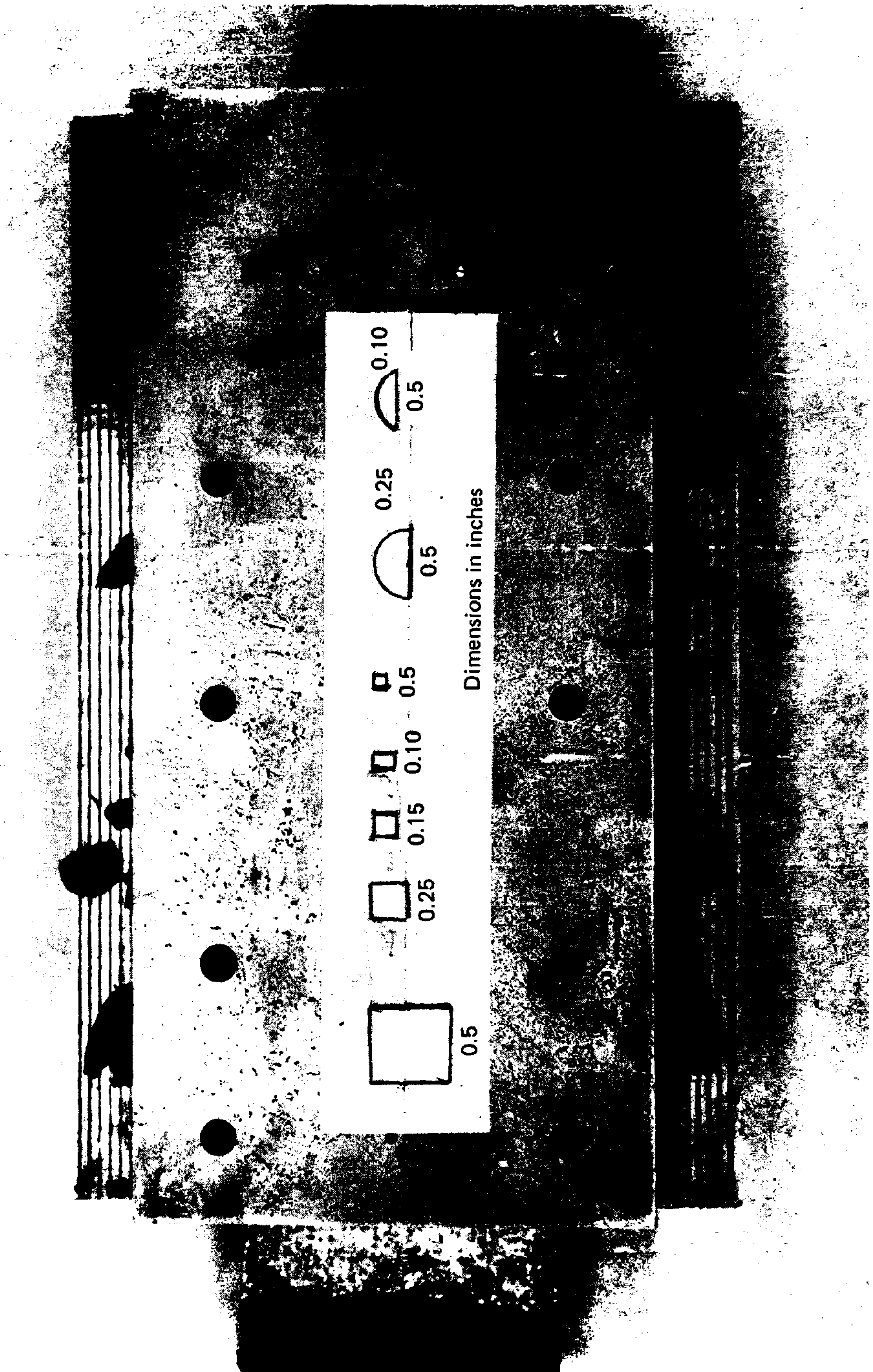


FIGURE 36.—EFFECT OF 450°F EXPOSURE ON DC 77-028 USED AS INJECTION SEALANT

TABLE 11.—EFFECT OF DIMENSIONS AND SHAPE ON RUPTURING OF FILLETS WHEN USING DC 77-028 AS AN INJECTION SEALANT

Injection hole		Fillet size (in.)	
Size (in.)	Shape	0.5 by 0.75	0.25 by 0.25
0.50 by 0.50	Square	Ruptured	Not tested
0.25 by 0.25	Square	Ruptured	Dislodged
0.15 by 0.15	Square	No visible damage	Dislodged
0.10 by 0.10	Square	No visible damage	Ruptured
0.50 by 0.25	Halfmoon	Ruptured	Dislodged
0.50 by 0.10	Halfmoon	Ruptured	Ruptured
0.50 by 0.05	Halfmoon	Ruptured	Bulged

TABLE 12.—EFFECT OF DIMENSIONS AND SHAPE ON RUPTURING OF FILLETS WHEN USING DC 77-066 AS AN INJECTION SEALANT

Injection hole		Fillet size (in.)	
Size (in.)	Shape	0.50 by 0.75	0.25 by 0.25
0.50 by 0.50	Square	Slight bulge	Not tested
0.25 by 0.25	Square	No effect	No effect
0.15 by 0.15	Square	No effect	No effect
0.10 by 0.10	Square	No effect	No effect
1.0 by 1.2 by 0.3	Right triangle	No effect	No effect
1.0 by 1.1 by 0.2	Right triangle	No effect	No effect
1.0 by 0.10 by 0.1	Right triangle	No effect	No effect

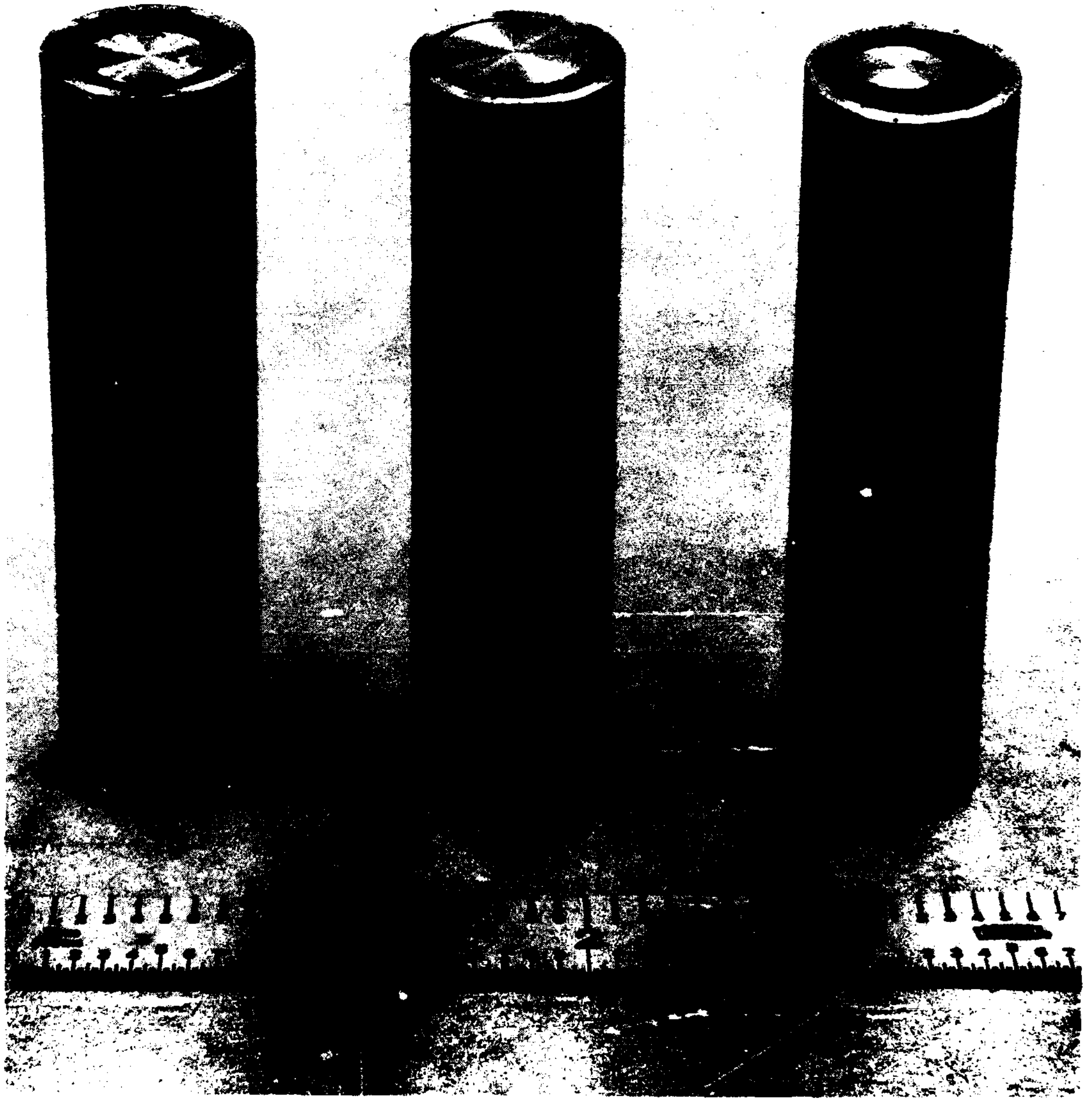


FIGURE 37.–THERMAL EXTRUSION TEST

TABLE 13.—EFFECT OF USE OF METAL PLUGS TO LIMIT EXTRUSION

Metal plug diameter (in.)	Extrusion (in.)
0.53	0.08
0.43	0.13*
0.33	0.15

*Another specimen extruded 0.22 in.

(H) Addition of 0.6 and 1.25% (by weight) Kapton foam did not eliminate thermal extrusion of DC 77-028. However, it was noted that increasing the amount of foam was effective in reducing extrusion.

(I) Functional test jigs with injection cavities (0.25 by 0.25 by 3 in.) were sealed with the following sealants:

(1) DC 77-028 filled 60% by weight with Cab-O-Lite. Cured at 250° F.

(2) DC 77-028

(3) DC 77-053

The above injection seals were leak free after cyclic heat and pressure exposures. Total exposures were:

(1) Twelve heating and cooling cycles. Seven of the cooldown periods were made faster by immersion in water.

(2) Aging at 450° F for 884 hr.

(3) Cyclic 0-15 psi for 2100 cycles. DC 77-028 with 4% Nitrosan developed leaks after the above exposure.

(J) Another set of functional tests with injection seals (0.25 by 0.25 by 3 in.) were conducted with the following materials:

(1) DC 77-028 filled with (0.125 in.) cubes of Nitrosan blown 77-028 foam (1.0 specific gravity). Mix ratio was approximately 50% by volume.

(2) DC 77-028 filled to 60% by weight with Cab-O-Lite. Cure was accomplished at 250° F.

(3) DC 77-028 with 5% Nitrosan.

(4) Stainless steel wool packing saturated with DC 77-028.

(5) DC 77-028.

(6) DC 77-028 with 5% Nitrosan and 16% glass beads.

(7) DC 77-028 with 2% chopped glass fibers.

(8) DC 77-028 with 3-in. length of 0.125-in. diameter stainless steel Tecknit tube.

(9) DC 77-028 with 27% PI powdered foam.

Test results are shown in table 14.

TABLE 14.–EFFECT OF VARIOUS ADDITIVES TO LIMIT EXTRUSION

Injection number	Total extrusion after first 450°F exposure	Initial leak test	Final leak test*
1	1/16 in.	Not tested	Not tested
2	Slight bulge	No leaks	No leaks
3	Slight bulge	No leaks	Leaking
4	1/16 in.	No leaks	Leaking
5	1/4 in.	No leaks	No leaks
6	Slight bulge	No leaks	Leaking
7	Slight bulge	Leaking	Leaking
8	Slight bulge	Leaking	Leaking
9	1/2 in.	No leaks	Leaking

*Four exposures to 450°F for a total of 48 hr and two exposures to 0- to 15-psi pressure cycle for a total of 1450 cycles

3.8 PICTURE FRAME SHEAR

The panels sealed with DC 77-028 were leak free after 10,736 hr of exposure to fuel vapor at 426° to 441° F in the accelerated cycle and after load cycles. This was true whether the panel was fillet sealed or faying surface sealed only. Small checks were noticed in the fillets.

The panel sealed with AFML 397 was leaking after approximately 3000 hr of such exposure. The sealant had hardened and cracked, and adhesion was lost.

3.9 SUSTAINED FILLET DEFLECTION

The gaps were 0.093, 0.099, 0.075, 0.079, 0.057, 0.060, 0.037, 0.042, 0.020, 0.021, 0.008, and 0.007 in. After 4900 hr of 400° F exposure all fillets except those covering the four smallest gaps had failed (more than 10% tear). AT 450°F for 4900 hr all except the one covering the 0.021-in. gap had failed. After 31 accelerated cycles, equivalent to 4500 hr of high-temperature exposure, only those covering 0.008 and 0.021 in. had not failed. Those over the 0.020- and 0.042-in. gaps were marginal.

3.10 DEFLECTION SIMULATOR

Dow Corning 77-028 deflection simulator specimens were tested with various deflections at 450°F. Results on unaged specimens after 100 cycles are as shown in table 15.

Exposure was continued for 20,000 cycles at a 0.011-in. deflection with no increase in crack length.

TABLE 15.—EFFECT OF CYCLING DEFLECTIONS ON FILLET TEARING

Deflection (in.)	Cracking (%)
0.025	33
0.020	32
0.015	24
0.011	22

3.11 FLIGHT CYCLE DEFLECTION

When the fillet deflection jig was removed from the flight cycle apparatus, two nuts were found to be free from the end of the actuator rod. The nuts were to cause the rod to provide full deflection to the sealant fillets. Because it cannot be ascertained when the nuts worked free, the total deflection cycles are not known.

Inspection of the fillets revealed a very small and equal amount of tearing at the base of the fillet in every case, indicating an invalid test.

3.12 BLOWOUT RESISTANCE

Test panels designed for blowout resistance tests were used to evaluate potential sealant applications on the off-pressure side of structures. A 0.125-in.-thick disk of DC 77-028 sealant was applied over holes of four different sizes and aged at 450° F for 1130 hr. The panels were installed so that pressure could be applied from the reverse side. Pressure was cycled and increased in 2-psi increments every 6 hr during 450° F exposure. Results are shown in table 16.

Another hole of 0.05-in. diameter was drilled into the test plates. A fillet of 0.25-in. thickness was applied to a plate which was not primed and another which was primed. Constant pressures of 10 psi and 100 psi were imposed at 450°F. Results are shown in table 17.

TABLE 16.—BLOWOUT RESISTANCE OF FILLETING SEALANT

Hole size (in.)	Pressure at failure (psi)
0.25	15
0.20	10
0.15	25
0.10	No failure after 14 hr at 30 psi Testing discontinued

TABLE 17.—EFFECT OF USE OF PRIMER ON BLOWOUT RESISTANCE

Test plate	Pressure (psi)	Comments
Primed	10	Leak free after 830 hr with no extrusion
Unprimed	10	Leak free after 830 hr with no extrusion
Primed	100	Sealant over 0.15-, 0.10- and 0.05-in. holes was leak free after 680 hr with no extrusion. Sealant over 0.20-in. hole was ruptured at an air bubble after 50 hr. Sealant over 0.25-in. hole failed by extrusion after 200 hr.
Unprimed	100	Sealant over 0.15-, 0.10- and 0.05-in. holes was leak free after 680 hr with no extrusion. Sealant over 0.20-in. hole was leak free with some extrusion. Sealant over 0.25-in. hole failed by extrusion after 200 hr.

3.13 REPAIRABILITY

Peel strength panels prepared as in section 2.3.1.5 were tested, with results as shown in table 18.

3.14 REPRODUCIBILITY OF DC 77-028

A comparison of the initial physical properties of different lots of DC 77-028 are shown in table 19.

TABLE 18.—REPAIRABILITY RESULTS

Exposure	Cleaning method	Primer	Peel strength (ppi)	Failure mode
3 weeks at room temperature	No cleaning	Yes	3.5	Sealant/ sealant bond line
3 weeks at room temperature	Vigorous scrub with cleaner per section 2.2.1 to remove surface gloss	No	35	Cohesive
1 accelerated cycle	Vigorous scrub with cleaner per section 2.2.1 to remove surface gloss	No	8.0	Sealant/ sealant bond line
1 accelerated cycle	Vigorous scrub with cleaner per section 2.2.1 to remove surface gloss	Yes	3.0	Sealant/ sealant bond line
1 accelerated cycle	No cleaning	Yes	3.0	Sealant/ sealant bond line

TABLE 19.—INITIAL PROPERTIES OF DOW CORNING 77-028

Lot number	Tensile strength (psi)	Elongation (%)	Hardness (Shore A)	Flow (in./2 hr)	Specific gravity
206177	685	235	37	–	1.373
1222	645	400	33	0.4	1.367
306161	775	250	38	–	1.362
1114	605	195	42	–	1.362
104158	670	310	25-27	0.3	1.375
205180	–	–	35	0.45	1.371
307291	–	–	25	0.1	1.380
205271	690	230	51-52	1.7, 1.35	1.37
207239	620	205	27-29	0.2	1.377
401117	625	298	31-35	<0.1	1.375

3.15 QUALIFICATION TESTS

Tests were partially completed to qualify DC 77-028 for filleting sealant, DC 77-053 for faying surface sealant, and DC 77-066 for injection and prepack sealant according to the requirements of the purchase control specification, XBMS 5-50 (appended). Results are shown in tables 20, 21, and 22.

TABLE 20.—CLASS B (FILLETING) SEALANT REQUIREMENTS

Property	Requirements	Results		
Nonvolatile content	Minimum of 95%	99.8		
Flow	Maximum of 0.5 in.	<0.1		
Extrusion rate	Minimum of 15 g/min	114		
Tack-free time	Tack free within 48 hr	8 to 16		
Durometer hardness	Minimum of 20 shore A Within 5 points of quality control value*	31-35		
Specific gravity	Maximum difference between specimens of 1.0% Specific gravity within 2.2% of quality control value*	1.37-1.38		
Tensile strength and elongation	Minimum tensile strength of 475 psi Minimum elongation of 200% Minimum of 80% of quality control value*	625 298		
Adhesion to titanium	Minimum peel strength of 5.0 ppi Minimum cohesive failure of 85%	25 100		
		Condition of 8.2.11.1		
		(a)	(b)	(c)
Resistance to heat and fuel	Minimum tensile strength of 200 psi Minimum elongation of 75% Minimum shore A hardness of 20 Maximum weight change of 10% Maximum volume change of 30%	485 112 40 -3.5 -3.7	523 225 30 +4.4 +7.9	570 135 40 -2.0 -1.3
Dynamic performance	(To be performed by Boeing) Less than 30% cracking Less than 5% adhesive failure	Not tested		
		Condition of 8.2.11.1		
		(a)	(b)	(c)
Repairability	Minimum peel strength of 5.0 ppi or a maximum sealant bond adhesive failure of 15%	5 100	6 100	5 100

*Required only for supplier quality control or purchaser acceptance tests.
Quality control values are listed in the QPL (see section 7.2).

TABLE 21.—CLASS C (FAYING SURFACE) SEALANT REQUIREMENTS

Property	Requirements	Results			
Nonvolatile content	Minimum of 95%	99.9			
Extrusion rate	Minimum of 15 g/min	114			
Work life	Sealant to remain fluid before curing Sealant to be tack-free solid after curing	Passed			
Durometer hardness	Minimum of 20 shore A Within 5 points of quality control value*	58			
Specific gravity	Maximum difference between specimens of 1.0% Specific gravity within 2.2% of quality control value*	1.77			
Tensile strength and elongation	Minimum tensile strength of 150 psi	212			
	Minimum elongation of 50%	65			
	Minimum of 80% of quality control value*				
		Condition of 8.2.10.2			
		(a)	(b)	(c)8.2.11.1 (a)	(c)8.2.11.1 (b)
	Minimum shear strength of 100 psi	223	140	296	368
	Minimum cohesive failure of 85%	95-100	80-100	90-100	90-100
		Condition of 8.2.11.1			
		(a)	(b)	(c)	
Resistance to heat and fuel	Minimum tensile strength of 100 psi	310	236	327	
	Minimum elongation of 30%	50	48	54	
	Minimum shore A hardness of 20	64	58	60	
	Maximum weight change of 10%	-3.7	+1.4	-2.1	
	Maximum volume change of 30%	-5.3	+4.0	-2.9	
Thermal extrusion and reversion resistance	No damage due to expansion	None	None	Not tested	
	Maximum of 0.1 in. permanent extrusion	Passed	0.3	Not tested	
	No reversion of the sealant	None	None		
Repairability	Minimum peel strength of 5.0 ppi or a maximum sealant bond adhesive failure of 15%	5 Passed	6 Passed	5 Passed	

*Required only for supplier quality control or purchaser · .eptance tests.
Quality control values are listed in the QPL (see sectior .2).

TABLE 22.—CLASS D (PREPACK AND INJECTION) SEALANT REQUIREMENTS

Property	Requirements	Results		
Nonvolatile content	Minimum of 95%	99.96		
Flow	Maximum of 0.25 in.	0		
Extrusion rate	Minimum of 15 g/min	36		
Durometer hardness	Minimum of 20 shore A *Within 5 points of quality control value**	64		
Specific gravity	Maximum difference between specimens of 1.0% Specific gravity within 2.2% of quality control value*	1.86		
Tensile strength and elongation	Minimum tensile strength of 200 psi Minimum elongation of 50% *Minimum of 80% of quality control value**	227 55		
Adhesion to titanium	Minimum shear strength of 100 psi Minimum cohesive failure of 85%	Not tested		
		Condition of 8.2.11.1		
		(a)	(b)	(c)
Resistance to heat and fuel	Minimum tensile strength of 100 psi Minimum elongation of 30% Minimum shore A hardness of 20 Maximum weight change of 10% Maximum volume change of 30%	396 43 74 — -3.6	340 47 65 — +2.8	432 48 68 — -1.5
Thermal extrusion and reversion resistance	No damage due to expansion Maximum of 0.1 in. permanent extrusion	Not tested	Failed Failed None	Not tested
Repairability (with DC 77-053; not tested with DC 77-028)	Minimum peel strength of 5.0 ppi or a maximum sealant bond adhesive failure of 15%	5 Passed	5 Passed	5 Passed

*Required only for supplier quality control or purchaser acceptance tests.
Quality control values are listed in the QPL (see section 7.2).

4.0 CONCLUSIONS

Comparison of the change of physical properties with time at 426°-441° F in fuel vapor in the accelerated cycle and the flight cycle reveals that, in each case, the values are reduced at about the same rate and to about the same level. Tensile strength, elongation, and hardness appear to remain stable for at least the 11,427 hr of this program and are adequate for acceptable performance. The continuing change of weight and volume, however, indicate a finite life of an unknown amount.

It is apparent that a correlation between accelerated cycling and flight cycling is possible, at least for the particular fluorosilicones tested. Such testing is useful for comparing or screening sealants but does not tell the whole story. Practical aspects, such as the need to use a primer, the use of fillet, faying, and injection or prepack seals in conjunction with each other, the application difficulties, and adhesion inconsistency are independent from the polymer itself but must be considered in predicting service life. These and other possible deficiencies, depending upon the particular sealing system, must all be investigated as was done in this program. The importance of functional testing, such as the tank tests where many factors are combined, was made evident. In this program the tank tests exposed some serious problems with the DC 77-028 system that must be overcome. Promotion and maintenance of adhesion, reduction of thermal expansion, and greater strength and toughness at the higher temperatures are all factors where improvement is needed.

Specifically, we may conclude the following in regard to the DC 77-028 fluorosilicone system:

- For adhesion to stainless steel alloys, a nickel cladding is required.
- For adhesion to aluminum, the aluminum must be clad.
- The sealant is resistant to all aircraft fluids expected to be encountered, except Phillips PFA 55B anti-icing fluid.
- The commonly used leak detection materials would have no adverse effect on the sealant if removed prior to any high-temperature exposure.
- Commonly used machining fluids are compatible with the sealant.
- Water and high-humidity exposure cause no degradation.
- The sealant does not cause stress corrosion of 6Al-4V titanium alloy in the annealed condition.
- Injection seals must be limited in both diameter and length to preclude extrusion, tearing, and reversion. No effective method has been found to solve this problem. The methods included adding different fillers, foaming agents, foam particles, and stainless steel wool packing.

- Fillets are not effective in sealing when the gap due to structural deflections exceeds 0.02 in.

- Holes or slots to be covered with sealant should not exceed 0.15 in. in width or length.

- The sealant is repairable if proper care is taken.

- Apparently the fillet thickness should be kept to the minimum necessary to ensure complete covering and sealing so that splitting and cracking can be avoided.

- Dow Corning can reproducibly manufacture DC 77-028 and can make production size batches.

- The DC 77-028 exhibits a service life greater than that of the AFML 397 fluorocarbon system. The embryonic nature of AFML 397 development is recognized.

5.0 RECOMMENDATIONS

Accelerated cycling, flight cycling, and tank tests should be continued using specimens from one lot of sealant and in sufficient number to produce statistically reliable data.

A program with Dow Corning should be put into effect to improve the DC 77-028 system, as discussed in section 4.

Attempts should be made to develop fuel tank sealants from polymers other than fluorosilicones, especially if aircraft designed to fly in excess of Mach 2.7 are contemplated. These sealants should be tested in the same way as DC 77-028 for comparison purposes.

APPENDIXES

1. SCOPE

a. This specification covers fuel and heat resistant synthetic rubber compounds for sealing airframe structure against passage of jet fuel or fuel vapor. These materials are suitable for exposure within the temperature range of -50°F to 440°F.

b. This specification requires qualified products.

2. REFERENCES

Except where a specific issue is indicated, the issue of the following references in effect on the date of invitation for bid, shall form a part of this specification to the extent indicated herein.

a.	ASTM D 297	Chemical Analysis of Rubber Products
b.	ASTM D 412	Tension Testing of Vulcanized Rubber
c.	ASTM D 471	Test for Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids
d.	ASTM D 2240	Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer
e.	D6-14016	Sealant Dynamic Performance Testing
f.	D6A-11873-1	Titanium Compatibility Testing: U-Bend Specimens
g.	ASTM D 1655	Specification for Aviation Turbine Fuels
h.	BMS 7-174	Titanium Alloy Sheet, Strip and Plate Ti-6Al-4V
i.	BMS 11-7	Cleaning Solvent, Pre-sealing

3. CLASSES AND DASH NUMBERS

a. This specification covers three classes of sealant. These are:

Class B - Sealant material for fillet sealing. The material shall be suitable for application by extrusion gun or spatula

Class C - Sealant material for faying surface sealing. The material shall be suitable for application by extrusion gun or spatula.

Class D - Sealant material for injection sealing. The material shall be suitable for application by extrusion gun.

b. A dash number shall be used in conjunction with the class designation to indicate a minimum application time in hours for two-component sealant materials. The application times are:

Class B - 2 hours

Class C - 48 hours

Class D - 2 hours

4. FORMS

The sealing material covered by this specification shall be supplied in bulk or kit form. The primer, if required, shall be supplied in bulk or aerosol form.

5. MATERIAL REQUIREMENTS

5.1 MATERIALS

a. The basic ingredient used in the manufacture of this product shall be a fuel resistant silicone rubber. The sealant may cure upon the addition of a separate curing agent (activator) to the base compound or by exposure to the atmosphere. Heat may be used to initiate cure of Class C-48.

b. A primer recommended by the manufacturer may be used to improve adhesion of the sealant. The primer shall conform to the requirements of Section 5.4.2.

c. The sealant and primer shall be suitable for application at ambient temperatures above 60F when the relative humidity is between 30 and 95%.

d. The sealant and primer materials must meet all requirements of this specification during the first 3 months after receipt provided storage has been at temperatures between 35^{o} and 80^{o}F in the original containers.

5.2 APPEARANCE

a. The base compound and activator of two-component sealant materials shall each be homogeneous and shall contain no skins, lumps, or excessive air. The activator shall possess sufficient color contrast to the base compound to permit easy identification of incompletely mixed sealing compound. Storage of the material shall cause no separation of ingredients which cannot be readily re-dispersed.

b. One-component sealant materials shall be homogeneous and shall contain no skins, lumps, or excessive air. Storage of the material shall cause no separation of ingredients.

5.3 TOXICITY

The compound shall contain no benzene, chlorinated solvents or materials of known vapor toxicity. The sealing compound or vapors emanating from it shall not cause discomfort or injury to any person engaged in application of the sealant under conditions of adequate ventilation and while exercising a reasonable degree of caution to avoid prolonged or repeated contact with the skin.

5.4 PHYSICAL PROPERTIES

5.4.1 Physical Properties of Sealants

When tested in accordance with Section 8, the sealants shall meet the requirements listed in Tables I, II, or III as applicable to the class designation of the material under test.

TABLE I

CLASS B SEALANT REQUIREMENTS

Property	Requirements	Test Description
Non-Volatile Content	Minimum of 95%	8.2.1
Flow	Maximum of 0.5 inches	8.2.2
Extrusion Rate	Minimum of 15 grams/minute	8.2.3
Tack-Free Time	Tack-free within 48 hours	8.2.5
Durometer Hardness	Minimum of 20 Shore A *Within 5 points of the quality control value	8.2.6
Specific Gravity	Maximum difference between specimens of 1.0% *Specific gravity within 2.2% of the quality control value	8.2.7
Tensile Strength and Elongation	Minimum tensile strength of 475 psi Minimum elongation of 200% *Minimum of 80% of the quality control value	8.2.8
Adhesion to Titanium	Minimum peel strength of 5.0 psi Minimum cohesive failure of 85%	8.2.9
Resistance to Heat and Fuel	Minimum tensile strength of 200 psi Minimum elongation of 75% Minimum Shore A hardness of 20 Maximum weight change of 10% Maximum volume change of 30%	8.2.11
Dynamic Performance	(To be performed by The Boeing Company) Less than 30% cracking Less than 5% adhesive failure	8.2.13
Repairability	Minimum peel strength of 5.0 psi or a maximum sealant bond adhesive failure of 15%	8.2.14

* Required only for Supplier Quality Control or purchaser acceptance tests. Quality Control values are listed in the QPL. (See Section 7.2)

TABLE II

CLASS C SEALANT REQUIREMENTS

Property	Requirements	Test Description
Non-Volatile Content	Minimum of 95%	8.2.1
Extrusion Rate	Minimum of 15 grams/minute	8.2.3
Work Life	Sealant to remain fluid before curing Sealant to be tack-free solid after curing	8.2.4
Durometer Hardness	Minimum of 20 Shore A *Within 5 points of the quality control value	8.2.6
Specific Gravity	Maximum difference between specimens of 1.0% *Specific gravity within 2.2% of the quality control value	8.2.7
Tensile Strength and Elongation	Minimum tensile strength of 150 psi Minimum elongation of 50% *Minimum of 80% of the quality control value	8.2.8
Adhesion to Titanium	Minimum shear strength of 100 psi Minimum cohesive failure of 85%	8.2.10
Resistance to Heat and Fuel	Minimum tensile strength of 100 psi Minimum elongation of 30% Minimum Shore A hardness of 20 Maximum weight change of 10% Maximum volume change of 30%	8.2.11
Thermal Extrusion and Reversion Resistance	No damage due to expansion Maximum of 0.1" permanent extrusion No reversion of the sealant	8.2.12
Repairability	Minimum peel strength of 5.0 ppi or a maximum sealant bond adhesive failure of 15%	8.2.14

* Required only for Supplier Quality Control or purchaser acceptance tests. Quality Control values are listed in the QPL. (See Section 7.2)

TABLE III

CLASS D SEALANTS REQUIREMENTS

Property	Requirements	Test Description
Non-Volatile Content	Minimum of 95%	8.2.1
Flow	Maximum of 0.25 inches	8.2.2
Extrusion Rate	Minimum of 15 grams/minute	8.2.3
Durometer Hardness	Minimum of 20 Shore A *Within 5 points of the quality control value	8.2.6
Specific Gravity	Maximum difference between specimens of 1.0% *Specific gravity within 2.2% of the quality control value	8.2.7
Tensile Strength and Elongation	Minimum tensile strength of 200 psi Minimum elongation of 50% *Minimum of 80% of the quality control value	8.2.8
Adhesion to Titanium	Minimum shear strength of 100 psi Minimum cohesive failure of 85%	8.2.10
Resistance to Heat and Fuel	Minimum tensile strength of 100 psi Minimum elongation of 30% Minimum Shore A hardness of 20 Maximum weight change of 10% Maximum volume change of 30%	8.2.11
Internal Extrusion and Reversion Resistance	No damage due to expansion Maximum of 0.1" permanent extrusion No reversion of the sealant	8.2.12
Repairability	Minimum peel strength of 5.0 ppi or a maximum sealant bond adhesive failure of 15%	8.2.14

* Required only for Supplier Quality Control or purchaser acceptance tests. Quality control values are listed in the QPL. (See Section 7.2)

5.4.2 Primer Properties

a. Color

The applied film of primer shall possess sufficient color to permit ready identification.

b. Drying Time

The primer shall dry sufficiently in 90 minutes at a temperature of 75 ± 5F and a relative humidity of 50 ± 25% to permit application of sealant.

c. The primer shall promote satisfactory adhesion of the sealant to titanium as determined by conformance of the sealant with the cohesive failure requirement of Section 5.4.1.

5.5 CORROSION OF TITANIUM (To be Performed by The Boeing Company)

When tested in accordance with 8.2.15, the sealant and primer shall cause no corrosion of the titanium test specimens.

6. QUALIFICATION

a. All requests for qualification shall be directed to a Materiel Department of The Boeing Company which will request data and samples when desired.

b. Data shall be submitted by a supplier desiring qualification indicating compliance with the requirements of the specification for the class of material for which qualification is desired. Test data supplied must show conformance with requirements of Section 5 specifically. Values for individual specimens and average values shall be reported. The test facilities (supplier or named test laboratory) used in determination of the data shall be indicated.

The supplier shall not be required to show conformance with the requirements of Paragraph 5.5. or with the requirements of Paragraph 5.4 which require testing per Section 8.2.13 or which require aging per Section 8.2.11.1.(c).

c. The supplier shall also furnish two gallons (volume) of the material with an appropriate amount of primer and activator (if required) for each class of material to be qualified. Samples shall be identified per Section 9.3, except in place of "Purchase Order Number" the identification shall be as follows.

Submitted by (name), (date) for Qualification Tests in accordance with the requirements of Specification XBMS 5-50 under authorization (reference authorizing letter).

d. After review of supplier data and Boeing tests of the samples submitted, the supplier will be advised as to whether product approval has been granted. Products which qualify will be listed in the Boeing Material Specification Qualified Products List.

e. The Boeing Company reserves the right to conduct a service application test prior to granting qualification approval.

f. No changes in raw materials or methods of manufacture shall be made without notification and prior written approval by the Division of The Boeing Company granting the original approval. Requalification of a revised material may be required and the supplier may be requested to provide a new designation.

7. QUALITY CONTROL

7.1 DEFINITION OF PRODUCTION BATCH AND LOT

A production batch is defined as all of the same production material which is made from all common lots of raw materials, manufactured at one time under the same manufacturing cycle (time and conditions), and identified accordingly by a specific batch number. A lot shall consist of one batch of sealant which is received under one purchase order.

7.2 QUALITY CONTROL VALUES

Quality Control values for durometer hardness, specific gravity, tensile strength and elongation are average values obtained during qualification tests for each sealant compound. These are listed with each sealant compound on the XBMS5-50 Qualified Products List.

7.3 SUPPLIER QUALITY CONTROL

A supplier shall not begin to furnish material to this specification until he has received written notice that he has been qualified to do so.

7.3.1 Test Reports

a. Production shipments shall be accompanied by a test report listing individual determinations for each test required by Section 7.3.2.

b. In the case where a single batch of material is used for more than one production shipment, copies of the test report for the first shipment may be used to satisfy the above requirements provided that the materials of subsequent shipments have been shipped within 3 months of the date of manufacture.

c. The test report shall also contain a statement that the formulation and manufacturing process for the production shipment are the same as those of the qualification sample.

7.3.2 Sampling and Tests

a. Each production batch of sealant shall be tested for conformance to the requirements listed in Table I, II, or III for flow, extrusion rate, durometer hardness, tensile strength, elongation, and tack-free time.

b. Each production batch of primer shall be tested for conformance with Section 5.4.2.c.

c. The material shall be randomly sampled so that test results are representative of the batch.

7. QUALITY CONTROL

7.1 DEFINITION OF PRODUCTION BATCH AND LOT

A production batch is defined as all of the same production material which is made from all common lots of raw materials, manufactured at one time under the same manufacturing cycle (time and conditions), and identified accordingly by a specific batch number. A lot shall consist of one batch of sealant which is received under one purchase order.

7.2 QUALITY CONTROL VALUES

Quality Control values for durometer hardness, specific gravity, tensile strength and elongation are average values obtained during qualification tests for each sealant compound. These are listed with each sealant compound on the XBMS5-50 Qualified Products List.

7.3 SUPPLIER QUALITY CONTROL

A supplier shall not begin to furnish material to this specification until he has received written notice that he has been qualified to do so.

7.3.1 Test Reports

a. Production shipments shall be accompanied by a test report listing individual determinations for each test required by Section 7.3.2.

b. In the case where a single batch of material is used for more than one production shipment, copies of the test report for the first shipment may be used to satisfy the above requirements provided that the materials of subsequent shipments have been shipped within 3 months of the date of manufacture.

c. The test report shall also contain a statement that the formulation and manufacturing process for the production shipment are the same as those of the qualification sample.

7.3.2 Sampling and Tests

a. Each production batch of sealant shall be tested for conformance to the requirements listed in Table I, II, or III for flow, extrusion rate, durometer hardness, tensile strength, elongation, and tack-free time.

b. Each production batch of primer shall be tested for conformance with Section 5.4.2.c.

c. The material shall be randomly sampled so that test results are representative of the batch.

7.4 PURCHASER QUALITY CONTROL

7.4.1 General Requirements

a. Each container in the shipment shall be inspected to determine compliance with the identification requirements of Section 9.

b. The supplier test report shall be reviewed to assure that compliance with all applicable requirements has been demonstrated.

7.4.2 Acceptance Tests

Purchaser Quality Control shall consist of any tests necessary to assure that production material meets the specification requirements and shall include acceptance tests listed below.

a. Sealant Material

Each lot of sealant shall be tested for conformance to the requirements listed in Table I, II, or III for flow, extrusion rate, work life, durometer hardness, specific gravity, and adhesion to titanium.

b. Primer

Each lot of primer shall be tested for conformance to Section 5.4.2.c with Class B sealant. The test may be conducted in conjunction with item (a) above.

7.4.3 Storage and Retest

Sealant and primer materials shall be retested as required during storage to ensure compliance with the requirements of this specification. The Quality Control Department of The Boeing Company shall determine the frequency of retesting and the specific tests to be performed.

7.4.4 Sampling Instructions

Samples shall be selected from each lot of material in a manner which will ensure that the samples are representative of the entire lot. Sample material shall be subjected to the acceptance tests listed in Section 7.4.2. The Quality Control Department of The Boeing Company may, if deemed necessary, request the supplier to submit a separate sample representing the shipment.

8. MATERIAL TEST METHODS

8.1 PREPARATION OF TEST SPECIMENS

8.1.1 Cleaning of Test Panels

All test panels and parts shall be cleaned by applying BMS 11-7 cleaner from clean polyethylene (or equivalent) squeeze bottles. The BMS 11-7 cleaner shall be applied directly from the bottle to the panel or part so that the entire surface is wetted. Clean gauze pads, which have been wetted with clean er, shall then be used to thoroughly scrub the surfaces to be cleaned. The solvent shall be wiped off, while wet, with clean dry gauze pads. This procedure shall be repeated as required to produce a clean surface. Each gauze pad shall be used for one scrubbing or drying application only. Cleaned panels shall not be stacked, but shall be covered with paper toweling or equivalent until used. Test panels and parts shall be used within 8 hours after cleaning.

8.1.2 Preparation of Two-Component Sealant Compounds

a. For the original qualification, mix the sealant per step b. For supplier quality control tests any suitable mix method may be used. For purchaser quality control tests, use one of the following mix methods:

   (1) Any machine mixing method which has been approved for production use.

   (2) The mix method per step b.

8.1.2 (Continued)

b. Prior to mixing, two-component sealant compounds shall be stored at 75 ± 5F for a sufficient time to allow the material to reach a state of equilibrium with that temperature. Stir the activator and base immediately prior to weighing. Mix as follows:

(1) Weigh onto a clean flat stainless steel plate or pan the correct amounts of base and activator immediately prior to mixing. Do not allow activator to contact the plate.

(2) Hand mix by folding and squeezing the sealant compound with a spatula. Mix for a minimum of 5 minutes and until sealant compound appears uniform.

(3) Spread the sealant compound on a clean flat stainless steel plate or pan so that the maximum depth is less than 1/2 inch. Vacuum degas the sealant compound for 10 minutes with an absolute pressure of 0.25 psi (0.5 inches of mercury) or less.

(4) Remove the plunger and plug the nozzle end of a cartridge for the Semco No. 250 gun. Scoop up sealant with a spatula, place it in the open end of the cartridge and drive it down by sharply rapping the nozzle end of the cartridge on something solid. Repeat until the cartridge is filled.

(5) Vacuum degas the filled cartridge for 5 minutes with an absolute pressure of 0.25 psi (0.5 inches mercury) or less. A plastic film may be used as an extension of the cartridge to prevent overflow of the sealant. Place the plunger in the cartridge using care to minimize air entrapment.

c. When required, sealant shall be put into refrigerated storage of -65F (or colder) immediately after being placed into the cartridges. In no case shall "dry-ice" be used for refrigeration. Sealant shall be stored at or below -65F for a minimum of 16 hours but not for longer than 72 hours. Condition the frozen sealant at -65 ± 5F at least 2 hours immediately prior to thawing. Thawing shall be accomplished by vertically immersing the frozen cartridges in a 90 ± 2F water bath for 10 minutes ± 30 seconds with the plugs installed and the upper end of the cartridge one inch above the liquid level. "Time zero" shall be defined as the time of removal from the water bath.

8.1.3 Application of Primer

When required for adhesion, a coat of primer shall be applied to the cleaned test panels. The primer shall be applied in a continuous coat and as uniformly as possible. If the primer is in bulk form, apply with a gauze pad. If the primer is in aerosol form, spray from a distance of 8 to 12 inches. The primer shall be dried for a minimum

8.1.3 (Continued)

Time of 90 minutes at a temperature of 75 ± 5F and a relative humidity of 50 ± 25% prior to sealant application. Protect the primed surface from contamination until sealant application. Clean and reprime if sealant application does not occur within 4 hours after primer application.

8.1.4 Environmental Control

Except as otherwise specified, all test specimens shall be prepared, cured, tested, and evaluated at a temperature of 75 ± 5F and a relative humidity of 50 ± 25%.

8.1.5 Standard Cure

All references to standard cure in this specification shall mean fourteen consecutive days at 75 ± 5F and 50 ± 25% relative humidity for Class B, and Class D sealant materials. Class C-48 standard cure shall be 6 ± 1 hours at 160 ± 10F. All testing of cured sealing compound shall commence not later than five days after completion of the standard cure. For supplier quality control tests or purchaser acceptance tests, the cure period may be reduced as long as requirements of Section 5.4 are met.

8.1.6 Preparation of Sealant Slabs

a. Sealant materials shall be prepared in accordance with Section 6.1.2.

b. The sealant shall be cast to a thickness of 0.125 ± .015 inch in a closed rigid mold lined with Teflon. The dimensions of the mold shall be such that 1/2 to 1 full sealant gun cartridge is required to fill it and the minimum width of the cured slab is 5 inches. For Class C and D sealants, the sides of the mold shall be metal.

c. Fill the mold by extruding the sealant from a sealing gun with a Semco $440 nozzle. The nozzle shall be freed of air by a preliminary extrusion of 2 to 3 inches of sealant. During the casting operation the tip of the nozzle shall be placed in an injection hole and shall not be removed until the mold is filled to excess.

d. After 96 hours cure at 75 ± 5F and 50 ± 25% relative humidity, Class B slabs shall be removed from the mold and placed on paper toweling, Class C and D slabs shall complete the standard cure in the mold.

8.2 TEST PROCEDURES

8.2.1 Non-Volatile Content

a. Sealant materials shall be prepared in accordance with Section 8.1.2.

b. A tared, open aluminum container shall be filled with 10 to 30 grams of sealant. The filled container shall be weighed and placed uncovered in a convection oven maintained at 160 $\pm$ 10F. After 24 $\pm$ 1 hours at this temperature, the sealant shall be cooled to 75 $\pm$ 5F and weighed. The non-volatile content shall be calculated as follows:

$$\text{Percentage of non-volatile content} = \frac{\text{Final weight}}{\text{Initial weight}} \times 100$$

8.2.2 Flow

a. Sealant materials shall be prepared and refrigerated per Section 8.1.2 such that the flow test starts at 30 $\pm$ 2 minutes after "Time zero."

b. The Class B test shall be conducted with a flow test jig as shown in Figure 1. Depth of plunger tolerance is critical and shall be controlled within the tolerance during all tests. The flow test jig shall be placed on a table with the front face upward and with the plunger depressed to the limit of its travel. An excess of the sealing compound shall be extruded from the application gun (fitted with a Semco #440 nozzle) into the recessed cavity of the jig. Care should be exercised to minimize the entrapment of air. The sealant shall not be worked with nozzle tip or spatula but shall be leveled flush with the block by scraping with a spatula in two passes (each starting at the center). Within 10 seconds after the leveling operation, the jig shall be placed in an upright position (plunger end up), and the plunger shall be immediately advanced to the limit of its forward travel. The flow measurement shall be taken after the sealing compound has cured tack-free. The flow shall be measured as the distance between the tangent to the lower edge of the plunger and the farthest point to which flow has advanced.

c. For Class D sealants, prepare one 0.25 $\pm$ .05 I.D. x 3.0 inch metal tube (aluminum, titanium, copper, or stainless steel) and clean per Section 8.1.1. An excess of the sealing compound shall be injected into the tube using care to avoid entrapping air bubbles. Smooth the sealant flush with both ends of the tube, Within 10 seconds after the smoothing operation, place the tube in the vertical position against a flat vertical surface and secure with tape. The flow measurement shall be taken after the sealing compound has cured tack-free. The flow shall be measured as the distance between the end of the tube and the farthest point to which flow has advanced out of the tube.

8.2.3 **Extrusion Rate**

Sealant material shall be prepared and refrigerated as described in Section 8.1.2 such that the extrusion rate test is started at the end of the specified application time (tolerance shall be ± 5%). A sealant gun cartridge shall be fitted with a Semco #440 nozzle having an orifice diameter of 0.125 ± 0.005 inches. The nozzle bore shall be smooth and free of flash or other protrusions. The cartridge shall then be inserted into the Semco sealing gun which is attached to 90 ± 2 psi air supply. Two or three inches of sealant shall be extruded to clear entrapped air prior to the actual flow-rate determination. The sealing compound shall be extruded into a tared container (sealant gun shall be operated at maximum flow rate) for a measured time interval of 60 ± 1 second. The extruded sealing compound shall then be weighed, and the weight, in grams per minute of flow, shall be recorded to the nearest gram. The extrusion time may be reduced as long as 20 grams or more are extruded during the test interval.

8.2.4 **Work Life**

a. Class C sealant material shall be prepared and refrigerated as described in Section 8.1.2. Prepare one 3 x 6 inch and two 1 x 6 inch metal panels (0.030 - 0.060 inch thick aluminum, titanium or stainless steel). Clean the panels per Section 8.1.1.

b. Apply a 1/32 to 1/16 inch layer of sealant to one side of the 3 x 6 inch panel. Expose the panel to ambient conditions for 1 hour. Place the 1 x 6 inch panels on the sealant layer and squeeze down with three "C" clamps on each panel within 2 hours of "Time Zero" as defined by Section 8.1.1. Remove the excess sealant.

c. At the end of the specified application time (tolerance shall be ± 2 hours) remove one of the 1 x 6 inch panels and determine if the sealant in the faying surface is fluid. Subject the 3 x 6 inch panel with the remaining 1 x 6 inch panel to the standard cure. After curing, remove the 1 x 6 inch panel and determine if the sealant in the faying surface has cured to a tack-free solid.

8.2.5 **Tack-Free Time**

After curing one Class B adhesion panel (Section 8.2.9.1) for 48 ± 1 hours, two 1-inch by 6-inch pieces of polyethylene film 0.004 ± 0.002 inch thick shall be applied to the sealant and held in place at a pressure of 1/2 ounce per square inch for 2 minutes. The strips shall then be slowly and evenly withdrawn at right angles to the sealant surface. If the polyethylene film peels cleanly from the sealant without deforming it, the sealant shall be reported as tack-free.

8.2.6 **Durometer Hardness**

a. Durometer hardness specimens shall be prepared by cutting two 1 x 2 inch pieces from a slab of sealant prepared per Section 8.1.6. The specimens shall have been a minimum of 1 inch from any edge of the slab. Type A durometer readings shall be taken with the specimens plied together.

b. Type A durometer hardness measurements shall be taken in accordance with ASTM D2240 using a Shore Instrument and Manufacturing Co. durometer. A durometer stand and a 1 kilogram weight shall be used and the readings taken at 15 seconds. Report the Shore A hardness as the arithmetic mean of the median hardness values of the individual specimens.

8.2.7 **Specific Gravity**

a. Prepare one slab of sealant per Section 8.1.6. For qualification tests cut the slab into 20 approximately equal specimens. For quality control tests, cut 3 approximately 1 x 3 inch specimens from different areas of the slab. Remove bubbles 1/8 inch or larger by smooth cuts.

b. Determine the specific gravity of each specimen using the hydrostatic method of ASTM D 297 with the following restrictions: (a) Dip the specimens in ethyl alcohol for 5 seconds maximum for elimination of bubbles. (b) Weight of the specimens shall be obtained 45 ± 5 seconds after immersion in water.

8.2.7 (Continued)

Calculate the percent specific gravity difference between the largest specific gravity, SP1, and the smallest specific gravity, SP2, as follows:

$$\text{Specific gravity difference } (\%) = \frac{SP1 - SP2}{SP2} \times 100$$

Calculate the average specific gravity of the specimens.

8.2.8 Tensile Strength and Elongation

Ultimate tensile strength and elongation shall be determined in accordance with ASTM D 412 using Die C and a jaw separation rate of 20 inches per minute. Five specimens shall be prepared and tested from a slab of sealant prepared per Section 8.1.6. Report the tensile strength and elongation as the average of the five specimens.

8.2.9 Adhesion To Titanium (Class B Only)

8.2.9.1 Details of Panel Preparation

a. Prepare the required number of 0.05 x 2.9 x 6 inch panels from titanium alloy (6AL-4V Ti) conforming to BMS 7-174 Condition 1, Type B. Prepare an equal number of 2.9 x 12 inch strips from 200 mesh stainless steel screen. (Aluminum screen and/or other mesh sizes may be used if peeling from the screen does not interfere with the measurement of cohesive strength.)

b. Clean the panel surfaces and screen per Section 8.1.1 and apply primer per Section 8.1.3.

c. Sealant materials shall be prepared in accordance with Section 8.1.2.

d. Apply sealant to approximately 5 inches at one end of the panel to a depth of 0.125 $\pm$ 0.025 and level using the peel panel jig shown in Figure 2. Impregnate the screen with sealant for approximately 5 inches on one end. The sealant-impregnated end of the screen shall be placed on the panel in such a manner that the loose unimpregnated end faces the end of the panel free from sealant. Smooth the screen down on the layer of sealant, taking care not to trap air under the screen. An additional 0.125 $\pm$ 0.025 inch coating of sealant compound shall be applied over the impregnated screen. Subject the specimens to the standard cure.

8.2.9.2 Environmental Exposure

Cured specimens shall be subjected to the following environmental exposure:

a. One specimen shall be stored at ambient conditions until tested.

b. One specimen shall be exposed to 500 $\pm$ 10F for 4 hours in a circulating air oven.

c. For qualification tests only, three specimens shall be exposed to the aging conditions required by Section 8.2.11.1. One specimen shall be exposed to each condition specified for the 42 $\pm$ 1 day or 6 cycle aging period.

8.2.9.3 Peel Testing of Panels

a. After exposure, two 1.0 inch wide strips shall be prepared on each panel by cutting completely through the screen and sealant to the metal length-wise along the panel and continuing completely along the unimpregnated screen. Cuts through the sealant under the screen shall be made so that an initial separation of sealant from the metal panel is promoted.

b. The loose end of each 1 inch wide strip in turn shall be clamped in one jaw of a suitable recording tensile testing machine and the adjacent end of the panel shall be fastened in the other jaw as shown in Figure 3. The screen shall be pulled at an angle of 180° from the panel and at the rate of 2 inches per minute in jaw separation.

c. Cuts in the sealant to the metal panel at the junction of separation shall be made in an angle of 45° towards the direction of separation at approximately 0.4 inch increments (approximately every 24 seconds) on the left side of the panel as shown in Figure 3. No cuts are required for 100% adhesive failure; however, any cohesive failure shall be treated as above. On the right side, except for the initial cut to promote separation, cuts shall be made only as necessary to prevent the sealant from peeling from the screen. All cuts shall extend completely across the strip being peeled and shall penetrate completely through the sealant to the panel.

d. The percent cohesive separation shall be determined from the ratio of cohesive separation area to total cohesive and adhesive separation on both test areas. The cohesive strength shall be determined during cohesive tear. The average of the cohesive strength, as determined from an extensiometer graph of the right side pull, shall be recorded. Values recorded during cutting or while load is being picked up after cutting shall not be included in the average. Panels which have been exvironmentally exposed shall be tested within 24 hours after removal from the exposure condition.

8.2.10 Adhesion to Titanium (Class C and D only)

8.2.10.1 Specimen Preparation

a. Prepare the required number of 0.050 x 1.0 x 3 inch panels from titanium alloy (6Al-4V-Ti) conforming to BMS 7-174 condition 1, Type B.

b. Clean the panel surface per Section 8.1.1 and apply primer per Section 8.1.3.

c. Sealant materials shall be prepared in accordance with Section 8.1.2.

d. Apply sealant to a one-inch square area at the one end of each panel. Assemble panels in pairs in the Shear Specimen Jig (Figure 4) so that contact pressure is maintained on the bonded area by means of retaining Angle B. Sufficient sealant shall be applied so that a continuous film of 0.011 ± 0.004 inch will be obtained when the retaining angle is bolted down. Subject the specimens to the standard cure. Remove the excess sealant.

8.2.10.2 Environmental Exposure

Cured specimens shall be subjected to the following environmental exposures:

a. Four specimens shall be stored at ambient conditions until tested.

b. Four specimens shall be exposed to 500 ± 10F for 4 hours in a circulating air oven.

c. For qualification tests only, twelve specimens shall be exposed to the aging conditions required by Section 8.2.11.1. Four specimens shall be exposed to each condition specified for the 42 ± 1 day or 6 cycle aging period.

8.2.10.2 Shear Testing of Panels

The shear test shall be performed within 24 hours after removal of specimens from the exposure condition. Pull the specimens apart in a tensile machine operating with a jaw separation of 2 inches per minute. Record the pull in pounds and the percent cohesive failure. Calculate the average shear strength for each set of four specimens.

8.2.11 <u>Resistance to Heat and Fuel</u>

8.2.11.1 Exposure and Test Schedule
Test after:

a. Aging in air at 425-440°F for 7, 21 and 42 days.

b. Immersion in fuel (ASTM D 1655 Jet A) in a closed container at 140 ± 10F for 7, 21 and 42 days. Suspend the specimens from one end during aging. Drain and replace the fuel once per week.

c. (To be conducted by The Boeing Company only): Exposure to 1, 3, and 6 cycles consisting of 16 ± 4 hours in fuel (ASTM D 1655 Jet A) at 140 ± 10F and 1 psia followed by 140 ± hours in fuel vapor at 1 psia and 425 - 440F.

8.2.11.2 Tensile Strength and Elongation

Prepare five tensile and elongation specimens per Section 8.2.8 for each aging period. Age the specimens per Section 8.2.11.1. Determine the tensile strength and elongation per Section 8.2.8 for each aging period.

8.2.11.3 Weight Loss and Volume Change

a. Four specimens for each aging period approximately 1 x 2 inches shall be cut from a slab of sealant prepared per section 8.1.6. Determine volume change for each specimen aged per Section 8.2.11.1 in accordance with ASTM D 471. Report the volume change for each aging period as the average of the four specimens.

b. The percentage weight loss shall be calculated from the volume change measurements as follows:

$$\frac{W_1 - W_2) \times 100}{W_1}$$

Where W_1 - weight of sample in air before aging.

W_2 = weight of sample in air after aging.

Report percentage weight loss for each aging period as the average of the four specimens.

8.2.11.4 Hardness

The Shore A durometer hardness of the weight loss and volume change specimens (8.2.11.3) for each aging period shall be taken in accordance with Section 8.2.6. Report the hardness change for each aging period.

8.2.12 Thermal Extrusion and Reversion Resistance

a. Prepare eight 0.25 ± .05 ID x 6.0 inch tubes from titanium (6Al-4V, 3Al-2.5V or CP). Clean the tubes per Section 8.1.1 and apply primer per Section 8.1.3. Inject an excess of sealant into the tubes, subject the specimens to the standard cure, and trim the sealant flush with the tube ends. Expose 2 specimens in each of the environments listed in Section 8.2.11.1 for 42 days or 6 cycles. The other specimens shall be stored for testing at the same time as the exposed specimens.

b. After the environmental exposure, examine the sealant at the tube ends for splitting caused by thermal extrusion. Measure the permanent extrusion of the sealant from the ends of the tube. Cut the tubes in half and examine the sealant for evidence of reversion to a liquid form.

8.2.13 Dynamic Performance (To be Performed by The Boeing Company)

a. A minimum of 16 test specimens prepared with Class B sealants shall be subjected to the Boeing Dynamic Performance Test (D6-14016). Prepare deflection plates from titanium alloy (6Al-4V Ti) conforming to BMS 7-174 Condition 1, Type B. Clean the plates per Section 8.1.1 and apply primer per Section 8.1.3. Inject Class B sealant into the special mold per D6-14016. Subject the specimens to the standard cure.

b. Expose half the specimens to 6 aging cycles per Section 8.2.11.1.c. The other specimens shall be stored for dynamic testing at the same time as the exposed specimens.

c. After the environmental exposure, half of the unaged and aged specimens shall be tested at -50 ± 5F. The remainder shall be tested at 440 ± 15F. Testing shall be in accordance with D6-14016. The deflection of the plates shall be 0.015 inch ± 0.001 inch. The specimens shall be subjected to 100 cycles. The specimens shall be removed, and the fillet cross sectioned perpendicular to its length. The percent of cracking shall be determined using the throat dimension as unity. Any adhesion failure shall be noted.

8.2.14 **Repairability**

a. Sealant materials shall be tested for adhesion with previously qualified sealant materials as required below:

Class of Material Under Test	Lower Layer per Step e	Upper Layer per Step f
B	Class B*	Class B**
	Class B*	Class B*
	Class B**	Class B*
	Class C**	Class B*
	Class D**	Class B*
C	Class C*	Class B**
	Class C*	Class D**
D	Class D*	Class B**
	Class C**	Class D*

* Sealant material under test.

** One set of specimens shall be prepared with each previously qualified sealant material in the class.

b. Prepare panels, and screen per Section 8.2.9.1.a.

c. Prepare the sealant materials in accordance with Section 8.1.2.

d. Clean the panel surface per Section 8.1.1 and apply primer per Section 8.1.3.

e. Apply the lower layer sealant to approximately 5 inches at one end of the panel to a depth of 0.125 ± 0.025 and level using the peel panel jig shown in Figure 2. Subject the specimen to the standard cure. Cured specimens shall be subjected to the following environmental exposures:

(1) One specimen shall be stored at ambient conditions while the other specimens are being aged.

(2) Three specimens shall be exposed to the aging conditions required by Section 8.2.11.1. One specimen shall be exposed to each condition specified for the 7 days or 1 cycle aging period followed by 1 day at 120F and 1 day at 250F.

8.2.14 (Continued)

f. Remove approximately 1/2 the thickness of the lower layer leaving a sealant surface without loose chunks or flaps. Clean the surface as follows:

(1) Vigorously scrub the sealant surface with clean gauze pads wet with BMS 11-7.

(2) Immerse the panel in BMS 11-7 for 30 minutes. Remove the excess solvent with dry gauze pads immediately after completion of the immersion. Dry the panel for a minimum of 24 hours at R.T.

(3) Repeat step (1) and continue scrubbing until the surface is uniformly dull. Dry the panel for a minimum of 1 hour at 75 ± 5F. Clean the screen per Section 8.1.1 and apply primer per Section 8.1.3. Using the upper layer sealant, complete panel preparation as described in Section 8.2.9.1.d.

g. Subject all the cured panels to 1 cycle of aging per 8.2.11.1.c.

h. Test the aged panels per Section 8.2.9.3. Measure the percent adhesive failure at the sealant bond line.

8.2.15 Corrosion of Titanium (To be performed by The Boeing Company)

a. Prepare 5 unnotched double U-bend specimens in accordance with D6A-11873-1. Clean the specimens per Section 8.1.1 and apply primer to 3 specimens per Section 8.1.3. Two specimens are to be retained as controls.

b. Prepared sealant materials in accordance with Section 8.1.2.

c. Apply sealant to 3 specimens as follows:

(1) For Class B sealants, load the specimens and the controls in accordance with D6A-11873-1.

(2) For Class C and D sealants, apply sealant to the bent portion of one mating surface. Within the application time, load the specimens and the controls in accordance with D6A-11873-1..

(3) Apply sealant approximately 1/8 inch thick on the exposed surfaces of the bent portion of the specimens. Subject the specimens to the standard cure.

d. Expose the specimens for 14 ± 1 day at 550F in air. Evaluate the specimens in accordance with D6A-11873-1.

9. PACKAGING AND MARKING

9.1 The base compound and curing agent (activator) shall be furnished in premeasured quantities in the correct ratio for use. The curing agent container shall be marked with the batch number of the base compound with which the curing agent shall be used, unless the curing agent is furnished in a container permanently attached to the base compound container.

9.2 Packaging shall be of such a nature so as to prevent damage during shipment or storage.

9.3 Each container shall be legibly and durably marked on the container body by printing or rubber stamping with the following:

a. Purchase order number

b. XBMS 5-50, revision letter, class and dash number

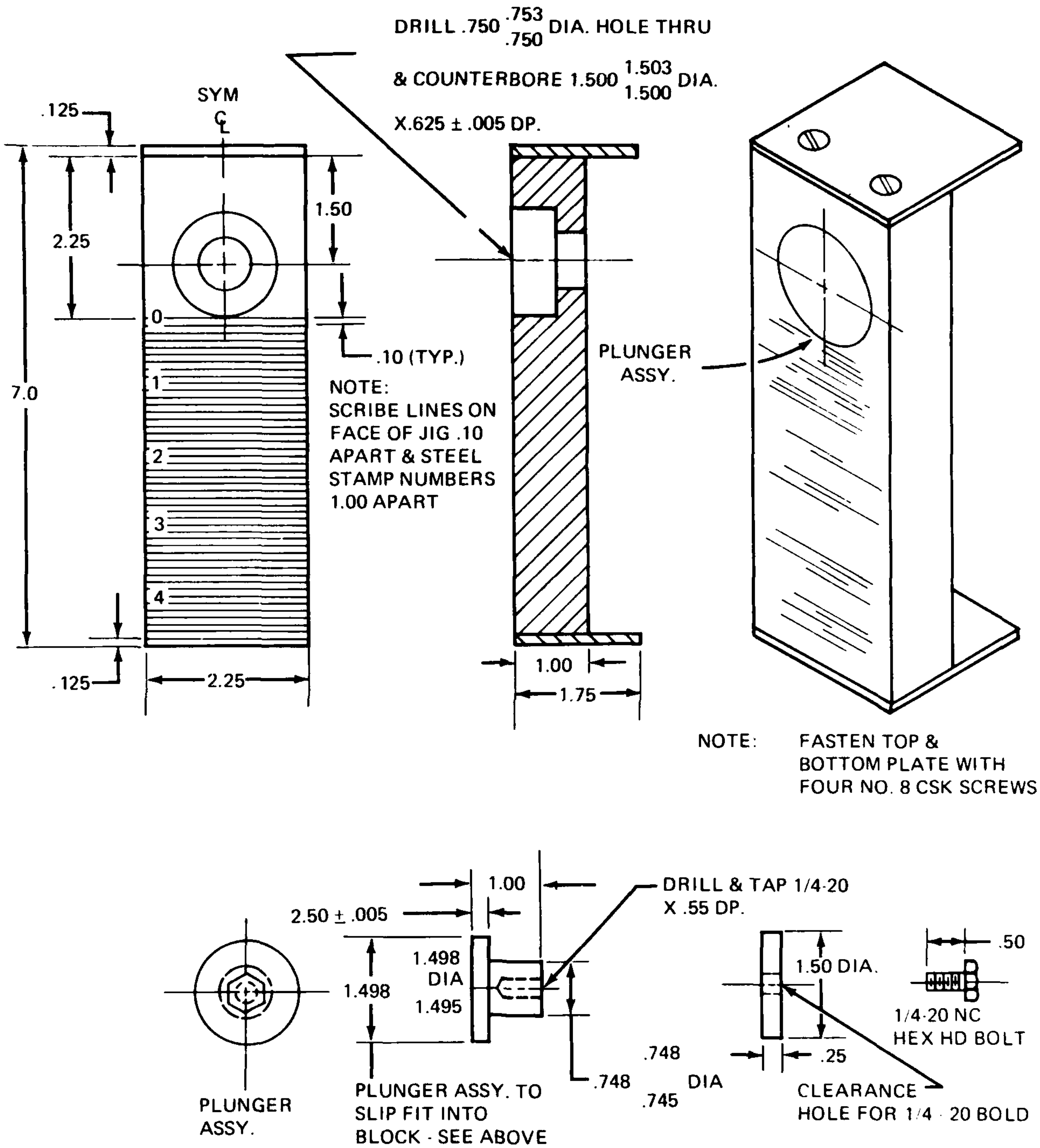
c. Manufacturer's name and compound number

d. Quantity

e. Mix ratio, when applicable, in parts of curing agent to 100 parts of base compound by weight and by volume.

f. Batch number of base and curing agent

g. Date of manufacture.



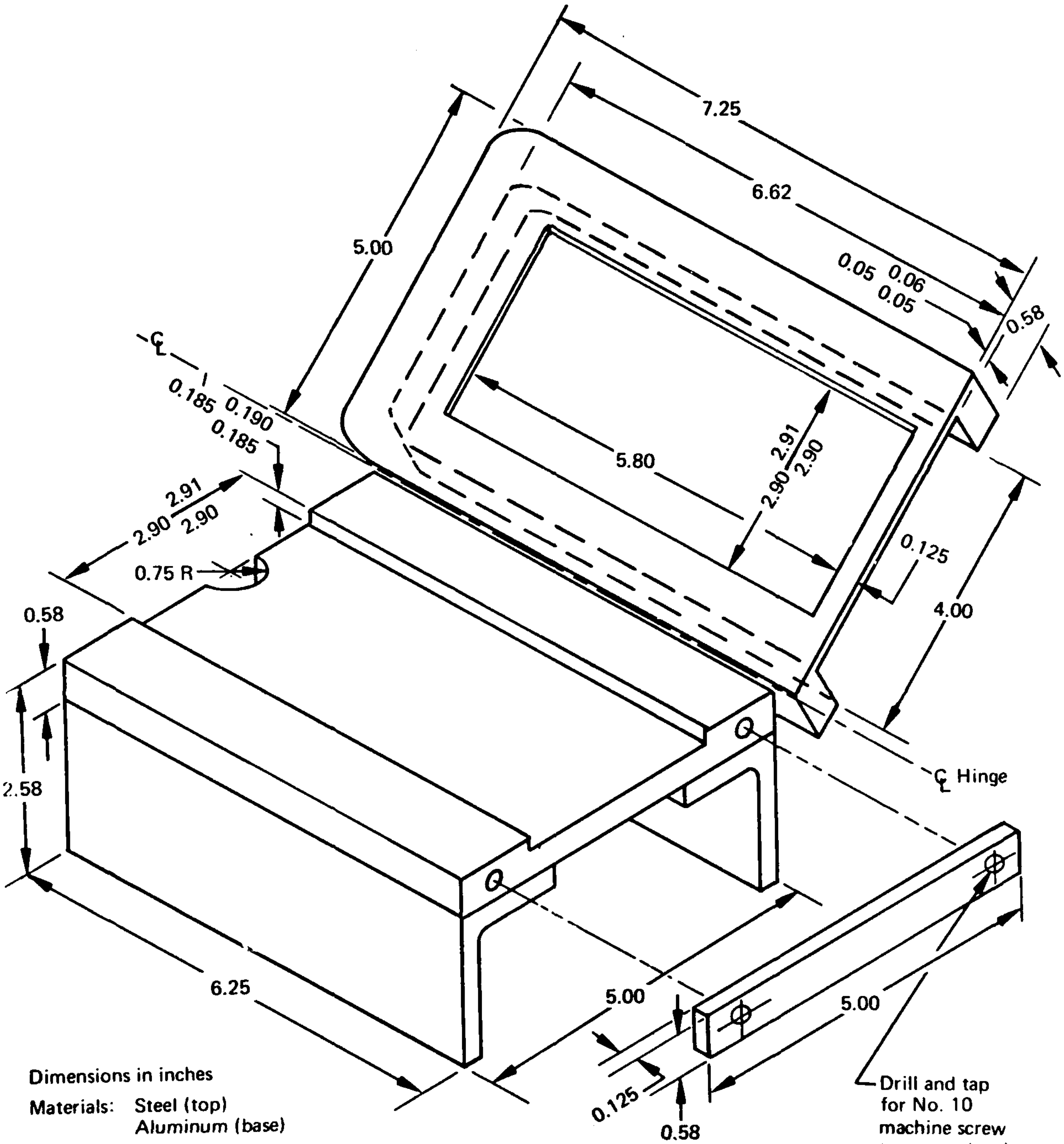
MATERIAL: ALUMINUM ALLOY

TOLERANCES: ± .03 (EXCEPT AS NOTED)

DIMENSIONS IN INCHES

FIGURE 1

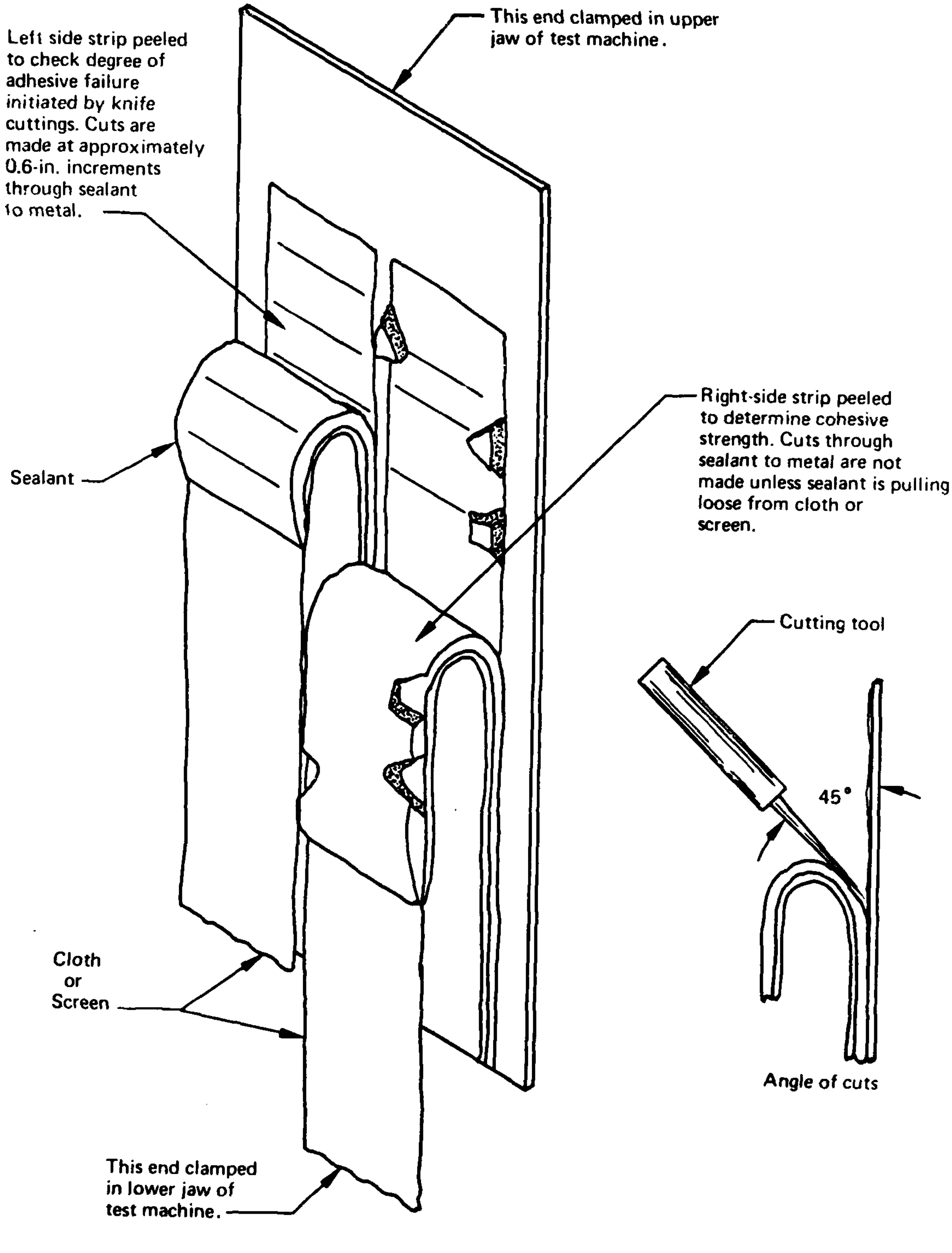
FLOW TEST JIG



Dimensions in inches

Materials: Steel (top)
Aluminum (base)

Tolerance: ±0.02 in.



Left side strip peeled to check degree of adhesive failure initiated by knife cuttings. Cuts are made at approximately 0.6-in. increments through sealant to metal.
This end clamped in upper jaw of test machine.
Sealant
Right-side strip peeled to determine cohesive strength. Cuts through sealant to metal are not made unless sealant is pulling loose from cloth or screen.
Cutting tool
45°
Cloth or Screen
Angle of cuts
This end clamped in lower jaw of test machine.

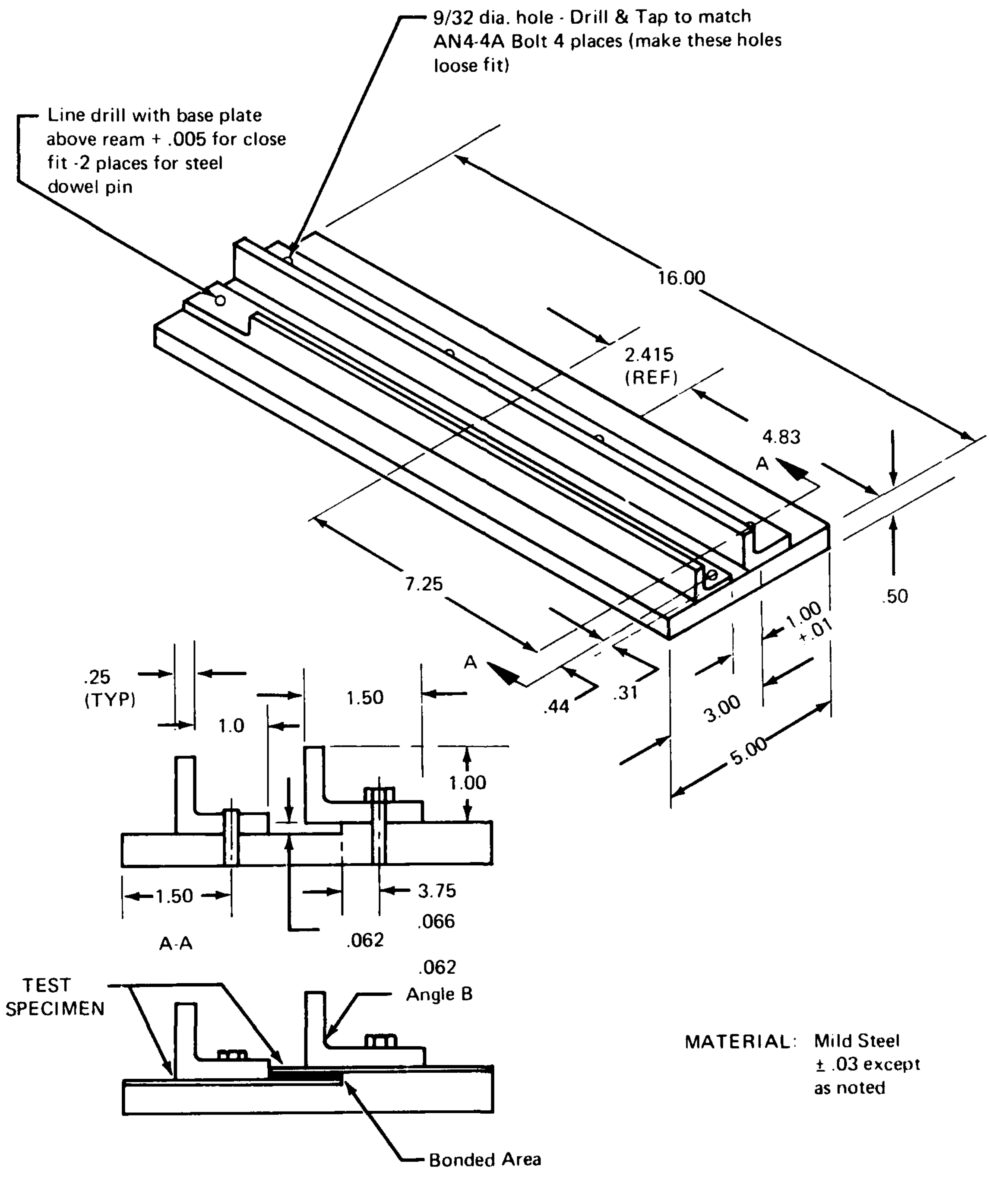


FIGURE 4
SHEAR SPECIMEN JIG

ORIGINAL ISSUE
REV

MATERIAL CLASSIFICATION	SUPPLIER PRODUCT DESIGNATION	SUPPLIER	QUALIFYING DIVISION	DATE
Class B	77-028	Dow Corning Corporation Midland, Michigan	CAG	2-9-71
	Quality Control Values:	Durometer Hardness, 35; Specific Gravity, 1.365; Tensile Strength, 625 psi; Elongation, 298%		
Class C	77-053	Dow Corning Corporation Midland, Michigan	CAG	2-9-71
	Quality Control Values:	Durometer Hardness, 58; Specific Gravity, 1.770; Tensile Strength, 212 psi; Elongation, 65%		
Class D	77-066	Dow Corning Corporation Midland, Michigan	CAG	2-9-71
	Quality Control Values:	Durometer Hardness, 64; Specific Gravity, 1.859; Tensile Strength, 227 psi; Elongation, 55%		
Primer for 77-028, 77-053, and 77-066	77-037	Dow Corning Corporation Midland, Michigan	CAG	2-9-71
		NOTE: The materials listed are presently undergoing qualification tests. Data will be available by 5-15-71, and this QPL is in effect until that date.		

1. SCOPE

a. This specification describes and controls the processes for fuel sealing of aircraft structure for elevated temperature service.

b. Certification of personnel is required.

2. REFERENCES

Except where a specific issue is indicated, the current issue of the following references shall be considered a part of this specification to the extent indicated herein.

a. ASTM D 2240 Test for Indentation Hardness of Rubber and Plastics by Means of a Durometer

b. BAC 5492 Machining and Cutting of Titanium

c. BAC 5748 Abrasive Cleaning, Deburring and Finishing

3. MATERIALS CONTROL

a. Cleaning Cloths 1

(1) Gauze, unsterilized, lint free	Johnson & Johnson or other sources
(2) Cheesecloth, lint free	Chicotec Mills, Inc. or other sources
(3) New white pipe cleaners	
(4) Cotton-tipped applicators (cotton swabs)	American Hospital Supply Division of AHSC

b. Cleaning solvents

(1) Cleaning solvent, Pre-Sealing, BMS 11-7	Qualified Products List
(2) Methyl Ethyl Ketone (MEK), TT-M-261	Any Source

c. Sealant, Integral Fuel tanks and Fuel Cell Cavities, XBMS 5-50 (Storage 35-80F)	Qualified Products List

1 These material shall conform to the following analysis:

(1) Acetone soluble material, 1.0% of dry weight maximum

(2) BMS 11-7 soluble material, 1.0% of dry weight maximum

Conduct tests in accordance with Federal Specification CCC-T-191, Method 2611 except:

(1) Conduct extractions using the solvents listed. Use a fresh sample for each solvent.

(2) The volume of BMS 11-7 remaining in the boiling flask at the end of the extraction cycle shall be less than 25% of the total solvent volume.

(3) Break off approximately 1 inch of the tips of the cotton swabs and extract only the tips.

(4) Subtract the weight of metal components of pipe cleaners from the dry weight prior to calculating the percent soluble material.

4. MANUFACTURING CONTROL

4.1 GENERAL REQUIREMENTS

a. All personnel involved in sealing operations or inspection of sealing must be trained and certified.

b. Restrict objects which may contact the areas being sealed. Clothing and tools are two examples of sources of contamination.

It is not acceptable to process sealants where inhibition of cure can take place. Cure of XBMS 5-50 sealants is inhibited by sulfur compounds (fumes from curing polysulfide sealants), amines (fumes from curing epoxies), and acidic compounds (fumes from curing one-component sealants).

4.2 SEALANT MATERIALS AND REQUIREMENTS

4.2.1 Fuel Sealant Materials

a. Fuel sealant materials are controlled by XBMS 5-50.

b. Three classes of sealants are controlled by this specification. The classes and their intended uses are listed below:

(1) Class B - Fillet Sealing

(2) Class C - Faying Surface Sealing

(3) Class D - Injection Sealing

The sealant used for each sealing method is specified in Section 4.5 or by drawing call-out.

c. A primer is required for adhesion. It is also controlled by XBMS 5-50.

4.2.2 Storage and Handling of Sealing Materials

a. Store all unmixed sealing compounds and primers at temperatures between 35 and 80F. The lower the temperature the longer the storage life.

b. Quality Control shall determine the frequency of retesting and the specific tests to be performed on sealing compounds and primers during storage.

4.2.3 Mixing and Packaging of Sealant Materials

a. Mixing and packaging of sealant materials shall be performed in a designated sealant mixing or packaging area.

b. Mix XBMS 5-50 sealing compounds as follows:

(1) Select the matched accelerator batch for the base compound of the sealant to be mixed.

(2) Stir the base and accelerator until homogeneous prior to measuring.

(3) Measure the base compound and accelerator to an accuracy of ± 2%.

(4) Mix the base and accelerator together until homogeneous.

c. Mixing and packaging methods shall produce sealant which is capable of meeting all of the requirements of XBMS 5-50. Samples of mixed sealant shall be subjected to the BMS acceptance tests as follows:

(1) Batch mixing process - Take one sample from each batch that is mixed. A batch for this requirement is defined as sealant mixed until homogeneous in one container at one time.

(2) Continuous mixing process - Take samples at the beginning of each run and again at the end of the run. Take an additional sample for each five gallons of material produced above 10 gallons. A mixing run for this requirement is defined as the period during which the mixing machine runs continuously (exception: Stopping to change sealant gun cartridges) with no changes in feed stock or adjustments.

d. Package sealant material in polyethylene sealant gun cartridges. Label polyethylene cartridges with the following information:

(1) Manufacturer's name, compound number and batch number.

(2) BMS Number, Type, Class, and dash number as applicable.

(3) Mixer operator's initials.

(4) Date and time mixed.

(5) Expiration date (See 4.2.4 for frozen storage requirements)

4.2.4 Storage of Mixed Compounds

a. Immediately after mixing, place the polyethylene cartridge filled with sealant and capped with polyethylene plugs or caps in a refrigerated chamber at -65F or colder.

b. Mixed sealant may be stored for up to six weeks at -65F or below. Presence of dry ice or a carbon dioxide rich atmosphere (greater than 2% by volume CO_2) for storage is prohibited.

4.2.5 Thawing Mixed Compounds

a. Thaw frozen sealant to produce 65F to 80F sealant temperatures. After thawing, remove all moisture from the surface of the cartridge.

b. Do not refreeze thawed sealant.

4.2.6 Application Time

a. Application time is the length of time during which the sealant remains workable after thawing. At 75F, XBMS 5-50 sealants are required to meet the following minimum application time:

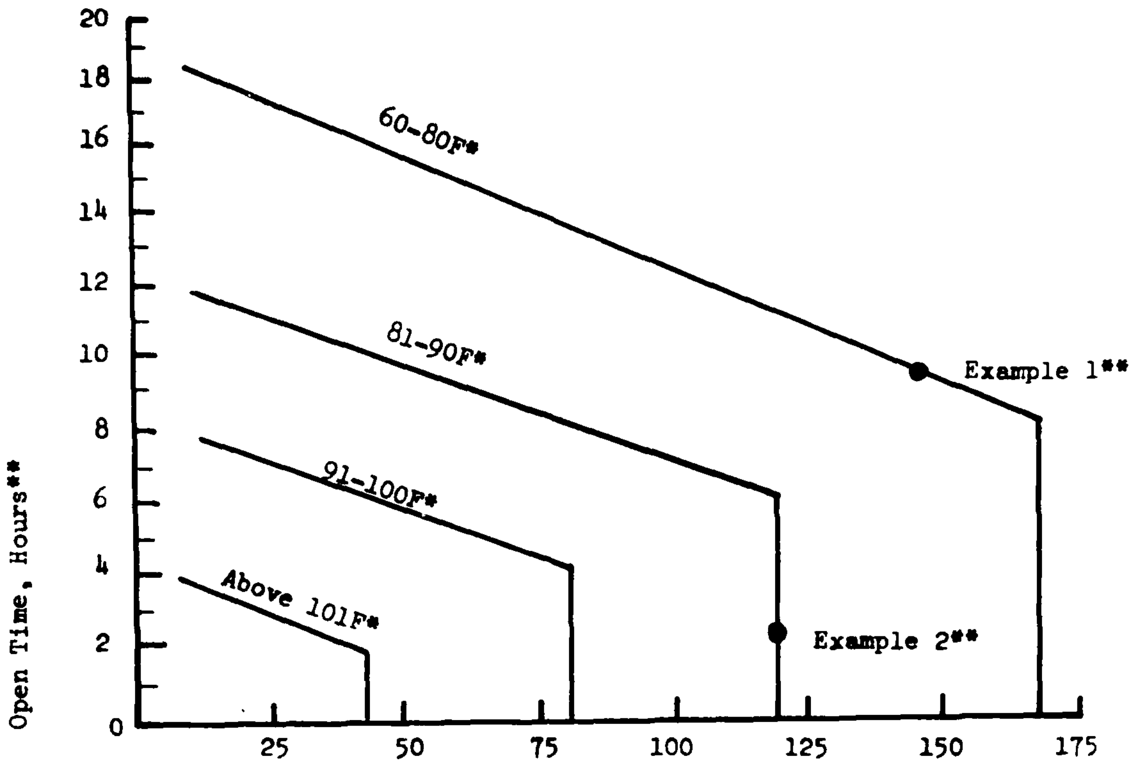
Class B - 2 hours
Class C -48 hours
Class D - 2 hours

b. Class B and D application time is dependent on temperature. Figure 1 shows the relationship between the approximate application time and temperature.

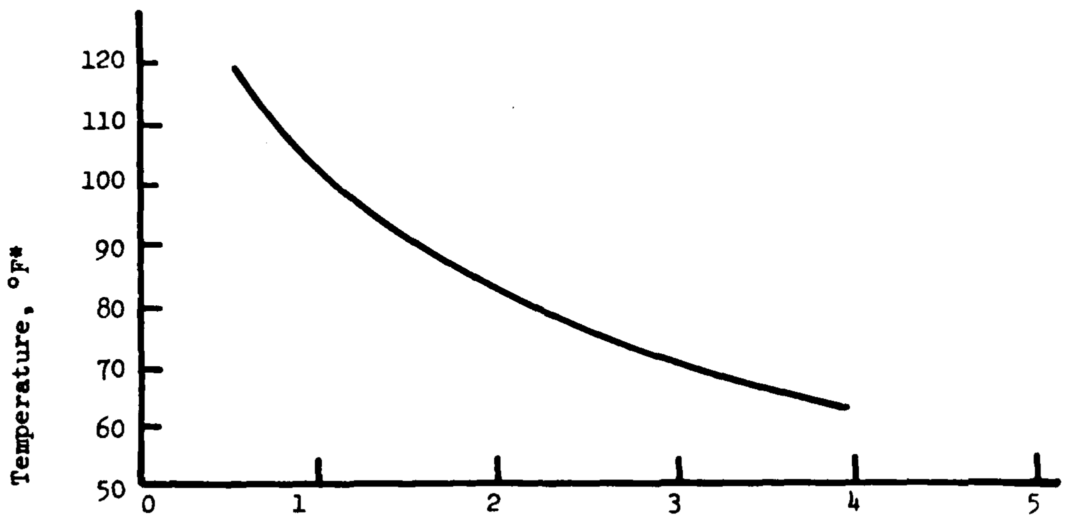
c. Class C squeez-out life is dependent on temperature and exposure to air. Figure 1 gives the application time, temperature and air exposure relationship. Open time plotted in Figure 2 is the time between extrusion of the sealant from the cartridge and sandwiching the sealant in the mating surfaces of the structure. Examples are given below:

Example 1 - The sealant is allowed to thaw in the shop at 70F. It is applied to the structure and after a 10 hour delay the structure is placed in the assembly position. From Figure 2, the squeez-out life is 140 hours.

Example 2 - The sealant is thawed in water at 90F. It is applied to the structure and after 2 hours the structure is placed in the assembly position. From Figure 2, the squeez-out life is 120 hours.



CLASS C Application Time, Hours (Squeeze Out Life)



CLASS B AND D Application Time, Hours (Squeeze Out Life)

APPLICATION TIME OF SEALANTS

FIGURE 1 AND 2

* The highest of ambient air, structure, or thawing medium temperatures.
** See Section 4.2.5.C

4.3 CLEANING

4.3.1 Preliminary Cleaning

4.3.1.1 Structure

Preliminary cleaning of structure shall be accomplished as follows:

a. Pick up loose fastener lubricant, dirt and chips by use of a vacuum cleaner or other means which does not smear or spread contamination.

b. Remove excessive soils from the surfaces using cleaning cloths wet with cleaning solvents. Persistent soils may be removed by abrasive cleaning in accordance with BAC 5748, except all precleaning and postcleaning shall be done in accordance with this specification.

WARNING Cleaning solvents are volatile, toxic and flammable.

c. For all fillet sealing vigorously scrub the surfaces with abrasive pads and cleaning solvents in accordance with BAC 5748. Use of fluids other than BMS 11-7 or MEK shall not be allowed when using abrasive pads.

d. After completion of scrubbing, remove residual contamination from the surfaces using cleaning cloths wet with cleaning solvents.

4.3.1.2 Sealant

Preliminary cleaning of sealant shall be accomplished as follows:

a. Be certain the sealant is cured in accordance with Section 4.7.2.

b. Cut fillet seals, which have not been tapered per Section 4.5.5.f, to provide a fresh scarfed face in accordance with Section 4.8.2.2.c.

c. Vigorously scrub the sealant with cleaning cloths wet with BMS 11-7 and continue scrubbing until the surface is uniformly gloss free. Allow the sealant to dry for a minimum of 60 minutes.

4.3.2 Final Cleaning

a. Final cleaning shall be accomplished as follows:

(1) Scrub the surfaces with a cleaning cloth dampened with BMS 11-7. Use a polyethylene squeeze bottle to dispense the cleaning solvent. The cloths shall not contain enough solvent to drip. Cleaning solvent shall not be poured or sprayed on the structure. All solvent shall be wiped off while wet, with a clean, dry cloth.

(2) Repeat the above procedure until there is no discoloration on the clean dry cloth.

(3) Always clean an area wider than the width of the finally applied primer and sealant.

(4) If necessary, remove all solvent from assembled faying surfaces using clean, dry and filtered compressed air. After removal with air, make a final cleaning with a cloth damp with solvent, but not dripping, and wipe dry.

(5) Channels and other "hard to get at areas" may be cleaned using clean small paint brushes, clean white pipe cleaners or clean white cotton swabs.

(6) Reclean the area if it becomes contaminated or if primer is not applied within 8 hours after final cleaning.

4.4 PRIMER APPLICATION

4.4.1 General Requirements

a. Final cleaning per 4.3.2 shall be accomplished prior to priming.

b. Do not apply or dry primer when it or the structure is below 60F. Relative humidity of the air in contact with the primed surface must be between 30 and 95%.

c. Minimum drying time for the primer coating is 90 minutes. Do not apply sealant until the primer has dried.

d. The primed surface is extremely sensitive to contamination. It is recommended that sealant be applied as soon as possible after the primer has dried. If there is any reason to suspect that contamination has occurred, if sealant is not applied within 8 hours after primer application, or if the dried primer coat is tacky, the primer shall be removed by cleaning per Section 4.3 and the surface reprimed prior to sealant application.

4.4.1 (Continued)

e. Primer supplied in large containers may be divided into smaller containers for use. The smaller containers shall be clean and dry with air tight lids. All containers shall be of metal or glass. Lid seals, if any, shall be of a material, such as polyethylene, which is insoluble in the primer and is not a source of contamination.

f. Keep all primer containers tightly closed when not in immediate use.

g. Discard the primer if any one of the following conditions occur:

(1) Eight hours have elapsed since the container was first opened for primer application.

(2) Less than one third of the original primer remains in the container.

(3) Slight cloudiness or gelling develops in the liquid primer.

(4) The dried primer coat is tacky.

h. Do not prime the surface of previously applied sealant or primer. This does not preclude a slight overlap onto existing sealant or primer to ensure coverage of metal surfaces. Where extensive overlapping of primer coats can occur, the old primer shall be completely removed in areas of potential overlap. This shall be accomplished by scrubbing vigorously in accordance with the cleaning procedure of Section 4.3.2.

CAUTION The sealant has very poor adhesion to unprimed metal and poor adhesion to primed sealant and excessive primer coats. It is a requirement that metal surfaces be completely primed with minimum overlap onto sealant and previously primed surfaces.

4.4.2 <u>Application of Primer</u>

a. Dampen the gauze, cotton swab or pipe cleaner with primer. The absorbent material shall not contain enough primer to drip.

b. Apply a uniform coating of primer to the surface. Scrub the primer into the surface with the gauze, cotton swab or pipe cleaner. Do not allow puddles of primer to form.

c. Primer must be applied to an area wider than the applied sealant.

d. Use a fresh gauze, cotton swab or pipe cleaner each time more primer is needed.

4.5 SEALANT APPLICATION METHODS

4.5.1 General Requirements

a. Do not apply sealant when it or the structure is below 60F. Relative humidity must be less than 95%.

b. Apply Class B and D sealants to titanium test coupons for tests used to determine compliance with the requirements of Section 4.7.2. Apply primer and sealant and cure the sealant concurrently with sealant application and cure on the structure. Prepare a minimum of one test coupon during each work shift for each combination of primer and sealant batches (manufacturer's batch) used during the shift. The test coupons shall be traceable to sealant applications on the structure.

4.5.2 Faying Surface Sealing

a. Complete all pre-assembly operations such as hole drilling, deburring, etc. Only cutting fluids per BAC 5492 are satisfactory for drilling if the parts are to be sealed.

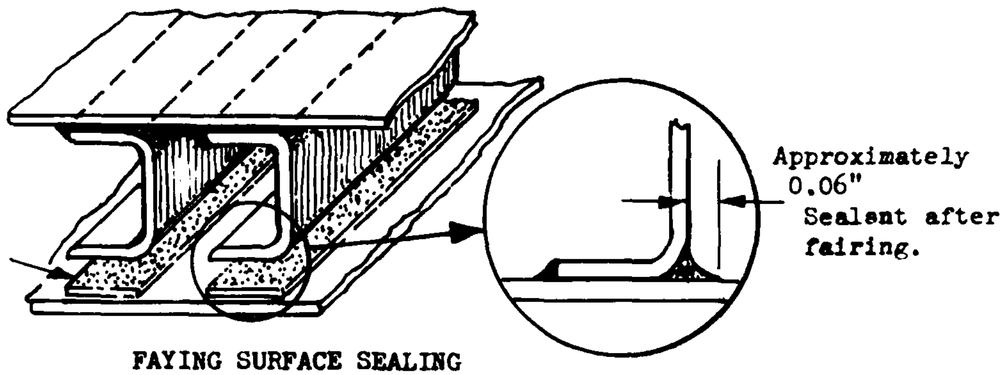
b. Clean (Section 4.3) and apply primer (Section 4.4) to both mating surfaces and areas where extruded sealant will be faired out. Primer is not required on fasteners and fastener holes.

c. Use XBMS 5-50, Class C or D sealant prepared per Section 4.2. Shop choice of Class C or D sealant depends on application time required. (See step f.(2)(a)).

d. Apply the sealant to one mating surface only and spread out so that the surface is entirely and uniformly covered. (See Figure 3). Use special caution to keep faying surface sealed areas free of chips, burrs or other foreign materials.

e. Place parts in assembly position. The sealant shall completely fill the space between the assembled faying surfaces. When the surfaces are fastened together, an excess of sealant shall be extruded so that a continuous bead is formed along the joint. Fair the sealant bead so that a continuous, smooth fillet of approximately 0.06-inch depth is formed along the joint. (See Figure 3). Remove the excess sealant so that fillet seals applied later will contact primed metal or the small fillet.

4.5.2 (Continued)



FAYING SURFACE SEALING

FIGURE 3

f. Permanent and Temporary Fastener Installation

(1) Install all permanent fasteners per the applicable process specification.

(2) If all permanent fasteners common to the seal cannot be installed within the minimum application time of the sealant (see Section 4.2.6), use temporary bolts as required to hold the parts firmly together. Torque the temporary bolts to the same minimum values required for the permanent fasteners.

CAUTION Gapping of structure can occur if the seal and squeeze out areas are not adequately fastened together within the application time of the sealant.

(a) Install a permanent or temporary fastener in each hole within the squeeze-out life (Class C) or application time (Class D) of the sealant.

(b) When temporary fasteners are removed to install permanent fasteners, removal of each individual temporary fastener shall be immediately followed by installation of a permanent fastener.

(3) If fasteners are not installed per Item (2)(a), MRB action is required.

g. Whenever possible, apply the fillet seals which contact the faying surface seals within the application time (see Section 4.2.6) of the faying surface sealant.

4.5.3 Pre-Pack Sealing

a. Do not substitute an injection seal for a primary pre-pack seal. An injection seal may be substituted for a secondary pre-pack seal.

b. Clean (Section 4.3) and apply primer (Section 4.4) to all surfaces of the cavity. Fasteners and fastener holes do not require priming.

c. Use XBMS 5-50, Class D sealant prepared per Section 4.2. Special cases requiring use of another class of sealant will be noted on the structural drawing.

d. Pack a small bead of sealant along each edge of the cavity.

e. Pack the entire void or cavity with an excess of sealant.

f. Complete the assembly so that the structural void is completely filled and an excess of sealant is extruded from the void.

g. Install fasteners in accordance with Section 4.5.2.f.

h. Remove the excess sealant and fair the exposed sealant.

i. Whenever possible, apply the fillet seals which contact the pre-pack seals within the application time (See Section 4.2.6) of the pre-pack sealant.

4.5.4 Injection Sealing

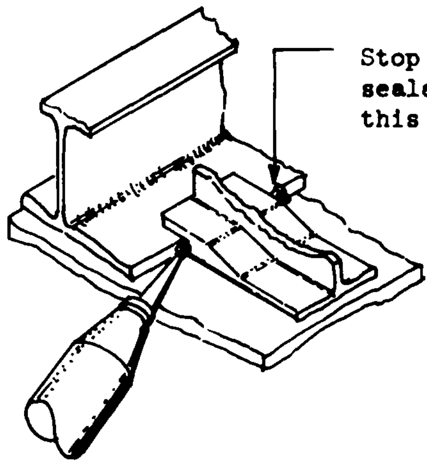
a. A pre-pack seal may be substituted for an injection seal.

b. Clean (Section 4.3) and apply primer (Section 4.4) to all surfaces which will be sealed.

c. Use XBMS 5-50, Class D sealant prepared in accordance with Section 4.2. Special cases requiring use of another class of sealant will be noted on the structural drawing.

d. Inject sealant into one end of the cavity or injection hole with a sealing gun until an excess of sealant emerges from the prescribed opening or openings. Fill the cavity completely with sealant. Exercise special precautions to use a sealant gun with sufficient capacity to ensure complete injection in one operation. (See Figure 4)

4.5.4 (Continued)



INJECTION SEALING

FIGURE 4

e. Remove the excess sealant and fair the ends of the injection.

f. Whenever possible, apply the fillet seals which contact the injection seals within the application time (See Section 4.2.6) of the injection sealant.

4.5.5 Fillet Sealing

a. Properly torque all bolts prior to filleting the periphery of the bolted structure or fitting. Do not fillet seal any parts until they are held together with permanent fasteners.

b. Clean (Section 4.3) and apply primer (Section 4.4) to all surfaces which will be sealed.

c. Use BMS 5-50 Class B sealant prepared in accordance with Section 4.2.

d. The sealant shall be applied with a sealing gun as described below:

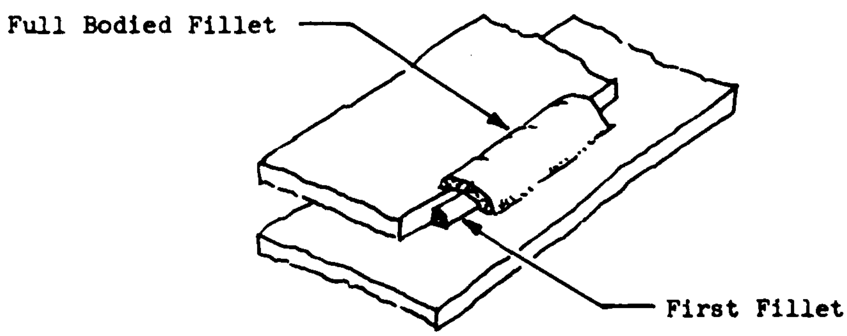
(1) Point the nozzle tip into the seam and maintain it nearly perpendicular to the line of travel. A bead of sealant shall precede the tip.

4.5.5 (Continued)

(2) Apply a small first fillet followed within 30 minutes by additional sealant to make the full bodied fillet as shown in Figure 5.

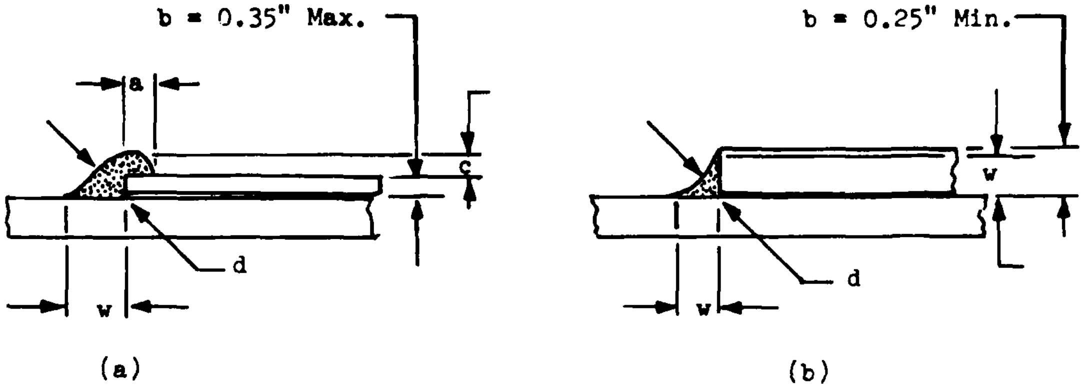
(3) The final fillet dimensions are shown in Figure 6. Work the fillet to final dimensions during the application time of the sealant.

(4) If a fastener will interfere with any fillet dimension, seal the fastener concurrently with the fillet sealant application. Blend the fastener fillet into the fillet seal. This requirement includes self-sealing fasteners.



FILLET SEALANT APPLICATION

FIGURE 5



d = 0.15" Min.
c = 0.06" Min.
w = 0.25 to 0.50"

w = 0.25 to 0.50"
d = 0.15" Min.

b Inches	a Minimum	a Maximum
0.01-.05	0.25	0.50
0.05-.15	0.20	0.40
0.15-.25	0.10	0.30
0.25-.35	0.10	0.25

When b = 0.25 to 0.35", the fillet may conform to either Figure (a) or (b).

FILLET DIMENSIONS

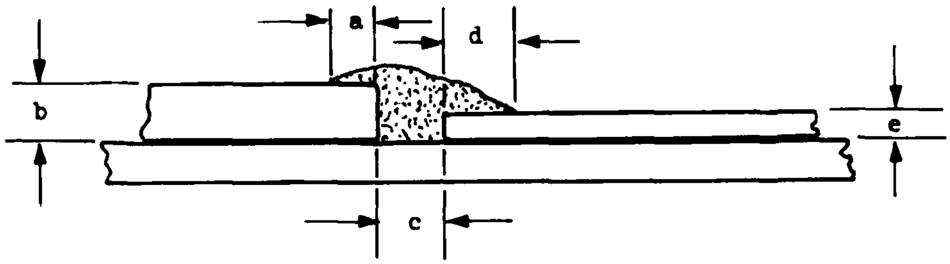
FIGURE 6

4.5.5.d (Continued)

(5) When a seal is made at the bottom of a slot, apply the sealant so as to fill the slot and maintain contact with the bottom and sides. (See Figure 7).

(6) Use care to see that folds, flaps, and entrapped air are not created during working. Work out air bubbles during the application time of the sealant.

(7) Re-entrant fillet edges are prohibited. (See Figure 8).

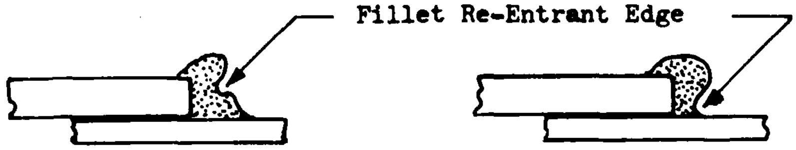


a + b = 0.25" to 0.50"   d + e = 0.25" to 0.50"

a and d = 0.10" minimum, except a and d = 0 when b, c, and e = 0.25" or more. The gap must be filled, not bridged.

SLOT SEAL DIMENSIONS

FIGURE 7

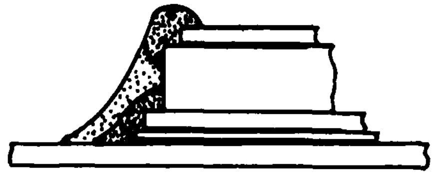


RE-ENTRANT FILLET EDGES

FIGURE 8

e. Where edges of multiple layers are fillet sealed, apply fillets as indicated in Figure 9. The individual fillets shall approximate the dimension given in Figure 6.

4.5.5.e (Continued)



MULTIPLE LAYER FILLET SEAL

FIGURE 9

f. When a fillet seal is stopped for any reason, do not stop it abruptly but taper it out. In cases where a fillet seal connects to an injection, pre-pack or faying surface seal, extend the full bodied fillet past the end of the injection, pre-pack or faying surface seal and then taper it out.

4.5.6 **Fastener Sealing**

4.5.6.1 Fastener Fillet Sealing

a. Clean (Section 4.3) and apply primer (Section 4.4) to all surfaces which will be sealed.

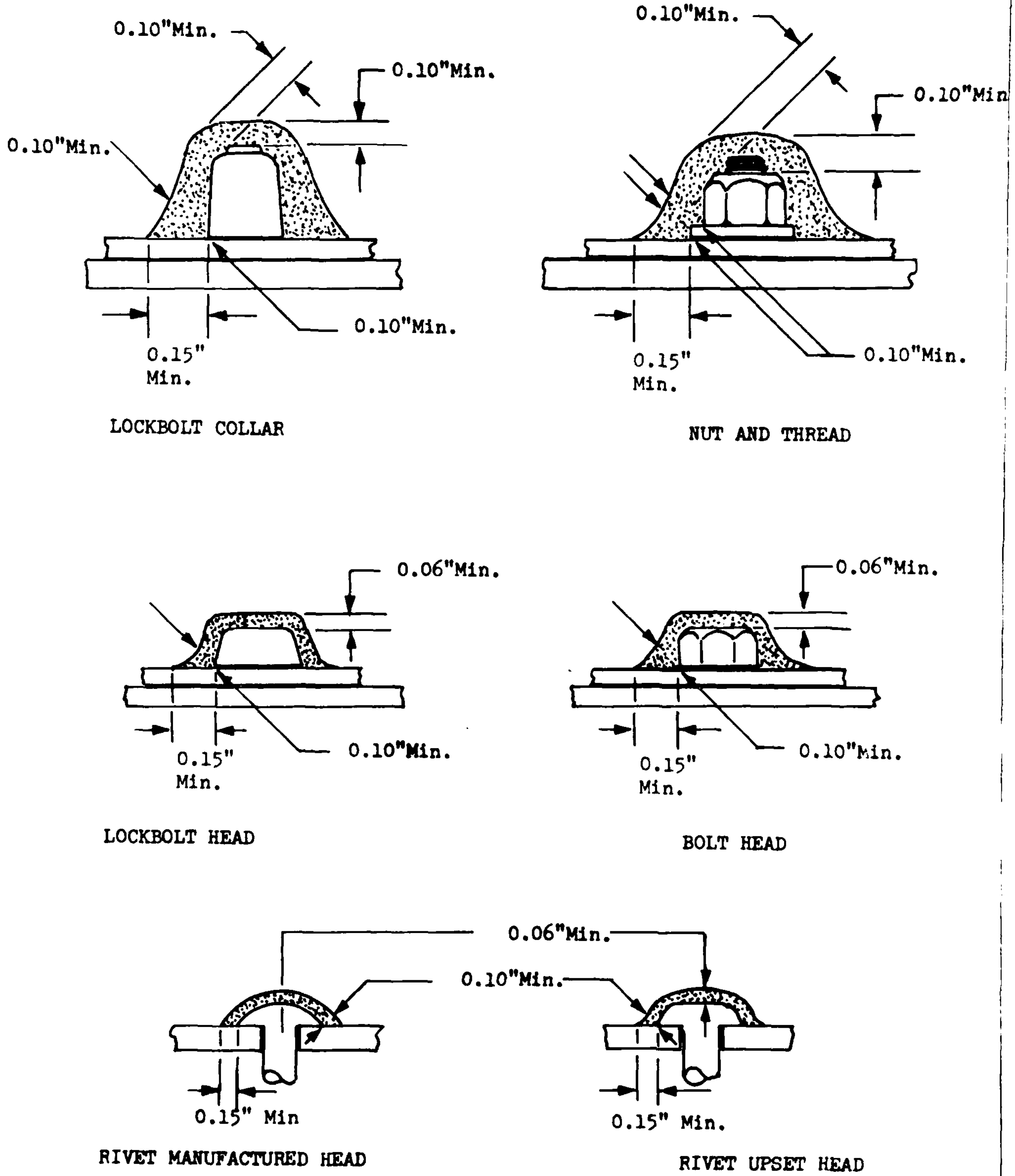
b. Use XBMS 5-50, Class B sealant prepared in accordance with Section 4.2.

c. Apply sealant around the base and over the fastener. Work the sealant so that the final dimensions conform to those given in Figure 10.

d. No voids or bubbles shall be allowed around the base of the fastener.

4.5.6.2 Seal Caps

This section will be completed when seal caps are available.



FASTENER FILLET DIMENSIONS
FIGURE 10

4.6 PROTECTION OF SEALING MATERIAL

a. Sealing materials shall be kept free of contamination by dust, oil, metal chips, or other contaminants.

b. Sealant must be protected against being dislodged, contaminated or damaged during operations subsequent to sealing.

c. Sealant which is contaminated or damaged shall be repaired in accordance with Section 4.8.

4.7 CURING

4.7.1 General Requirements

a. Cure of sealant shall be monitored by use of test coupons (See Section 4.5.1.b) until the requirements of Section 4.7.2 are met.

b. Failure of the sealant to meet the production cure requirements (Section 4.7.2) within the production cure times specified in Table I shall be cause for MRB action.

4.7.2 Production Cure Requirements

a. Class B and D sealants have cured sufficiently for normal production handling when the following conditions are met:

(1) The surface of the sealant is tack-free.

(2) The Type A (Shore A) durometer 5 second hardness of the sealant is 20 or more when measured in accordance with ASTM D 2240.

(3) The sealant fails cohesively when peeled from the surface of the appropriate test coupon.

b. Faying surface seals (Class C or D) may be subjected to normal production handling immediately after installation except special precautions must be taken to avoid contamination of the small fillets.

c. Curing times required for sealants to meet the requirements of Item "a" are given in Section 4.7.4.

4.7.3 Sealant Cure for Operational Usage

a. Cure of the sealant shall be completed prior to exposure to the service environment.

b. Minimum cure times for each sealant are listed in Section 4.7.4

4.7.4 Curing Conditions

a. Curing times and temepratures are listed in Table I.

b. Temperatures listed in Table I are for the sealant and the structure immediately adjacent to the sealant.

c. Condensing water on the sealant and/or structure is prohibited until the sealant has completed cure for operational usage.

TABLE I

SEALANT CURE TIMES AND TEMPERATURES

TYPE OF CURE	SEALANT CLASS	STANDARD CONDITIONS		ACCELERATED CONDITIONS	
		TIME, HRS	TEMPERATURE, °F	TIME, HRS.	TEMPERATURE, °F
Production	B and D	24 - 96	Factory Ambient (60F, minimum)	2 - 4	180 ± 20
	C	6 Minimum	180 ± 20	---	---
Operational Usage	B and D	2 weeks minimum	Factory Ambient (60F, minimum)	10	180 ± 20
	C	6 Minimum	180 ± 10	---	---
Operational Usage (alternate)	B and D	---	---	1 hour @ 180 ± 20°F plus 30 minutes @275 ± 25°F	

4.8 SEALANT REPAIR

4.8.1 General Requirements

a. Any sealant repair which may result in deviations from the drawing shall require MRB action and approval prior to accomplishing the repair.

b. Cleaning, priming and application of sealant shall be in accordance with the requirements of Sections 4.3, 4.4 and 4.5.

c. Sealant and structure which has been exposed to fuel shall be treated in accordance with Section 4.8.2 to remove residual fuel.

4.8.2 Removal of Residual Fuel

WARNING Fuel is flammable. Approval of detailed procedures by Safety and SST Propulsion Staff is required.

a. Remove all excess fuel by draining or mopping.

b. Remove sealant as required in Section 4.8.3. Scarf all fillets (Section 4.8.3.2.c(2)) in all areas where fresh sealant will contact existing fillets.

c. If the fresh sealant will not contact existing sealant, rinse the residual fuel from the faying surfaces using cleaning solvents and complete with repairs as required in Section 4.8.3. Maintain circulation of fresh air in the repair area so that the curing sealant will not be exposed to an accumulation of fuel vapors.

d. If the fresh sealant will contact existing sealant or if adequate air circulation cannot be maintained per Item c, subject sealant and adjacent structure to six hours minimum at 350 ± 25F.

e. Vigorously scrub the sealant surface with clean gauze pads wet with BMS 11-7 solvent.

f. Keep the sealant wet with BMS 11-7 for 30 minutes using solvent soaked cleaning cloths.

g. Immediately after completion of step (f), wipe the sealant with dry gauze pads to remove excess solvent. Allow the sealant to dry for a minimum of 24 hours.

h. Complete repairs as required in Section 4.8.3.

4.8.3 Repair of Damaged, Substandard or Contaminated Sealant

4.8.3.1 Repairs Within the Application Time

a. Perform repair of damaged or substandard applications of sealant by one of the following:

(1) Rework the sealant with a fairing tool.

(2) Add sufficient sealant and rework until the sealant configuration meets the specification requirements. For faying surface and pre-pack seals, additional sealant must be added to one of the mating surfaces. For injection seals, any reinjection of sealant must be sufficient to completely replace the first injection.

(3) Remove the damaged sealant, cure the remaining sealant (Section 4.7), clean (Section 4.3) apply primer (Section 4.4) and apply fresh sealant (Section 4.5).

4.8.3.1 (Continued)

b. Perform repair of contaminated sealant by one of the following:

(1) When the contaminant is a dry solid, remove the contaminant with an excess of the surrounding sealant. Complete repairs in accordance with Step (a).

(2) When the contaminant is clean solvent or clean water, remove the excess with cleaning cloths. Repair in accordance with step (3) or allow the sealant to cure, and repair, if required, in accordance with Section 4.8.3.2.

(3) When the contaminant is an oil or liquid of unknown composition, remove the contaminated sealant, cure the remaining sealant (Section 4.7), clean (Section 4.3), prime (Section 4.4) and apply new sealant.

4.8.3.2 **Repair After the End of the Application Time**

a. Cure the sealant in accordance with Section 4.7.2.

b. Repair undersized sealant fillets by cleaning the metal and sealant (Section 4.3), priming (Section 4.4) adding new sealant (Section 4.5) and fairing it into the existing sealant fillet so that the prescribed configuration is met.

c. Repair damaged or faulty fillet seals as follows:

(1) Remove all damaged or faulty sealant to ensure solid residual material and additional sealant as required to place the sealant splice in an area where access for cleaning is adequate. The fillet seals may be either completely removed or notched cleanly in the affected areas.

CAUTION Cutting tools shall be made from aluminum, hardwood or plastic and shall contain no abrasive materials.

(2) Wire brushing (BAC 5748, Class 3) may be used to remove residual sealant from the metal. Cut sealant so as to provide a smooth continuous scarfed face with adequate notching for access. (See Figure 11). Remove loose chunks or flaps of sealant on cut areas.

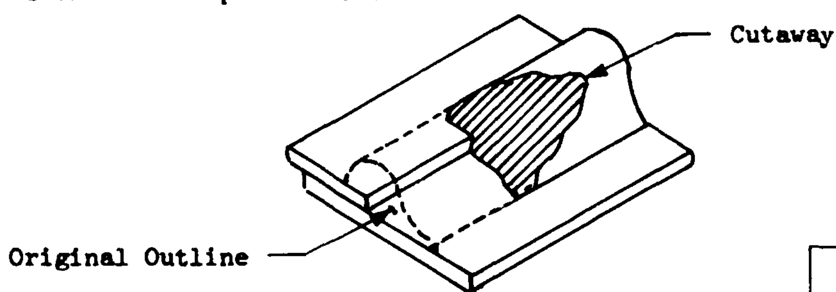


FIGURE 11. SCARFED FILLET SEAL

4.8.3.2 (Continued)

(3) Clean the sealant and metal (Section 4.3). Prime (Section 4.4) and apply new sealant (Section 4.5). Slight overlapping of the fresh sealant onto the existing full bodied fillet is satisfactory. A large buildup of sealant shall not be allowed.

d. When faying surface or pre-pack seals are replaced, completely remove the sealant. Clean (Section 4.3), apply primer (Section 4.4) and apply fresh sealant (Section 4.5.2 or 4.5.3).

e. Repair injection seals as follows:

(1) Primary injection seal - MRB action and approval required prior to accomplishing the repair. Follow the procedures for repairing secondary injection seals as described in (2).

(2) Secondary injection seal - Completely remove the sealant. Clean (Section 4.3), apply primer (Section 4.4) and apply fresh sealant (Section 4.5.4.).

f. Repair contaminated sealant as follows:

(1) Remove solid contaminants and examine the sealant for damage. Repair damaged sealant as described in step (c), (d), or (e).

(2) Remove liquid contaminants immediately with clean gauze. If the liquid contaminant is cleaning solvent or water, no further action is required. Other liquid contaminants require MRB action.

5. QUALITY CONTROL

A. Quality Control shall monitor the accountability and handling system to assure the continuous (time and temperature) control of sealant material from receiving through shop storage and use.

B. Quality Control shall verify proper clearances between parts per the applicable structural drawing before sealing operations.

C. Quality Control shall be responsible for determining the number of test coupons to be prepared in accordance with Section 4.5.1 and for assuring traceability of the coupons to sealant application on the structure.

D. Quality Control shall be responsible for testing required in Sections 3.a, 4.2.2, 4.2.3, and 4.7.1.